Volume 24 JULY, 1940 Number 7

BULLETIN
of the
American Association *of* Petroleum Geologists

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of the

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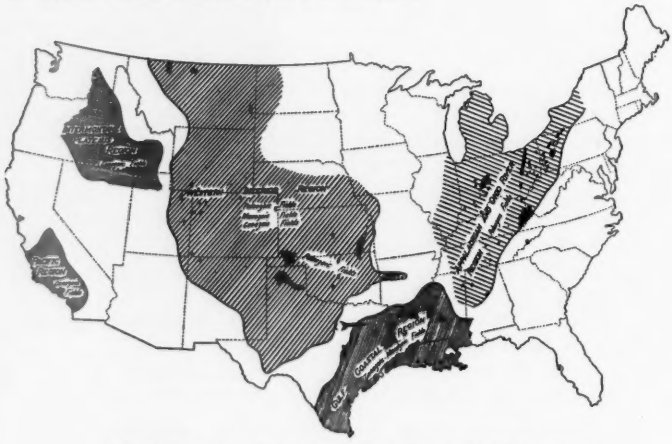

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Volume 24 Number 7

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JULY, 1940

ADDRESS OF WELCOME AT THE TWENTY-FIFTH ANNUAL MEETING OF THE ASSOCIATION[1]

M. M. LEIGHTON[2]
Urbana, Illinois

"There is a desire common to all men, to want to know."

These words of Aristotle express the deep intellectual instincts of the founders of The American Association of Petroleum Geologists, their desire to create a means of assembling information and airing views, and out of them to construct theories and concepts that would promote the science of petroleum geology.

During the history of mankind, there have been two kinds of schools which have arisen from time to time. One has been for the purpose of restoring a previous condition of high attainment, such as the old Greek school of Pythagoras which sought the recovery of the moral purity of past times; the other has been for the purpose of developing something new in man's attainments. Akin to this was the organization of The American Association of Petroleum Geologists which is directed toward the development of the science of Petroleum Geology. The former seeks *reformation;* the latter contemplates *creation.*

Twenty-four years ago, rapidly advancing industry and the great World War were pressing for increased supplies of petroleum. Companies were turning more and more to Geology to assist in the finding of hidden reserves. It was a new day for the science just as it had been a new day when the hunt was on for metalliferous deposits. It was a pioneering venture, another one of those fighting borders to human experience. The existing professional societies were absorbed in their own objectives and the necessity of a new one was compelling. The need justified the step. What can now be said of the results?

First, a wealth of valuable descriptive literature covering diverse

[1] Presented before the Association at Chicago, April 10, 1940.

[2] Chief, Illinois State Geological Survey Division.

geologic provinces and new types of structural occurrence; second, a growth of concept from the simple "closed" anticlinal theory to a varied structural control; third, an accumulation of fundamental data bearing on the origin and evolution of petroleum; fourth, changes in concepts regarding the migration and accumulation of petroleum; fifth, a marked stimulation of such branches of Geology as Dynamic Geology, Stratigraphy, Paleontology (particularly Micro-Paleontology), Sedimentation, Structural Geology, and Historical Geology; and sixth, contributions to the development of Geophysics, Geochemistry, and Petroleum Engineering.

It has been said that "Every new idea recreates the earth." Many such ideas have been born in the sessions of this Association.

It has also been said that "A new thought is as new as newly discovered territory." What company possessing a geological staff can not testify to this statement! And what scientific government officials whose duties are related directly to the discovery and development of the natural resources of our states and our nation can not realize the verity of this truth!

In other words, out of this phenomenal development of the science of Geology, partly through facilities provided by this Association, has come a corresponding increased economical development for the country as a whole.

Educationally, our institutions of learning have benefited. The courses now offered in General Geology, as well as those in Petroleum Geology, are far superior to those of twenty-five years past. These institutions have also grown in enrollment, opportunity for employment of their graduates has increased, the staffs of their departments have become more specialized, and emphasis upon fundamental training in Mathematics, Physics, and Chemistry is greater.

Why have I taken occasion to recall these matters? The reason is that I desire to convey to you, Mr. President and members of the Association, on behalf of the alumni and faculty of the University of Chicago, Northwestern University, and the University of Illinois, on behalf of the Illinois Geological Society which is sponsoring this meeting, and also on behalf of the Illinois Geological Survey which endeavors to coöperate in every way possible with the petroleum industry, our deep appreciation of the value of your Association to science, industry, and humanity, and, therefore, our very sincere welcome to you. We hope that your next quarter of a century will bear the same creditable testimony of your devotion to productive research and dissemination of knowledge as the past period has borne, and that your new members will be just as alert to recognize new concepts.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 7 (JULY, 1940), P. 1159

THE RESPONSE

HENRY A. LEY[1]
San Antonio, Texas

Dr. Leighton and the Illinois Geological Society! We of The American Association of Petroleum Geologists and the kindred societies met here deeply appreciate your enthusiastic sponsorship of our twenty-fifth annual meeting, the cordiality of your welcome, the comprehensive program you have arranged for us, and your wisdom in selecting Chicago and the Stevens Hotel.

Dr. Leighton! We had a purpose in selecting you to make this address of welcome. We wished thereby to pay a tribute to the Illinois Geological Survey, its capable director, and its personnel who have helped us immeasureably through the past years. All of us believed that our addresses of welcome come properly from aggressive men within our own organization.

Here, we are in a province of highly dynamic petroleum prospecting—probably the most active in the United States to-day. In these uncertain days we should never lose sight of the fact that the pioneering spirit of rugged men and women builded this nation.

All around us to-day there is evidence of youth—the Illinois Geological Society and your oil fields. As The American Association of Petroleum Geologists approaches the close of its first quarter-century we can well look about us to seriously dedicate our second quarter-century to those qualities of leadership and vision which have brought this geological province into spectacular prominence.

You, the Illinois Geological Society, are young and virile. So is The American Association of Petroleum Geologists. Youth and vitality are the driving forces of constructive dynamic ideas and interests that create and build long-enduring living structures. You can be rightly proud of your record in the fields of petroleum prospecting and petroleum geology. You can be equally proud of your accomplishments in planning and executing this annual A. A. P. G. meeting. On behalf of the Association, its sincere thanks.

[1] President of the Association.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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MEMORIALS[1]

ED. W. OWEN[2]
San Antonio, Texas

During the past year the Association has suffered a severe loss in the death of three of its past-presidents, Donald C. Barton, George C. Matson, and Ralph D. Reed. All of these men had played a prominent rôle in the development of petroleum geology and in the advancement of our Association. They did not reach their high positions at the expense of other men, instead they added much to the success and happiness of their fellow workers during the course of their own progress. It is not for their considerable material accomplishments that we now honor them, but for those qualities of character which made them great.

Donald Barton was nominated for the presidency of this Association several years ago and was overwhelmingly defeated. He did not permit that defeat to lessen in the slightest degree his interest in its activities or his efforts to further every forward movement of his profession. No slightest show of resentment against the men who stood in his way ever cast a shadow over his willingness to coöperate with all who were trying to add to the store of scientific knowledge and its effective use. It was inevitable that he should later be rewarded with that presidency, which he regarded as an opportunity for greater service rather than as an honor which he had gained. To those who were associated with him on the executive committee, his practical approach to every problem and his constant devotion to the human rather than the technical side of professional life were in sharp contrast to his superficial appearance of a cold, aloof, abstract scientist.

George Matson was one of the most unassuming and unobtrusive of men, and yet his outstanding ability was apparent to the most casual observer. During part of his career he was in charge of an organization of considerable size. As an executive he was distinguished by his ability to stimulate an unusual amount of independent, constructive effort from his men and by his scrupulous care in seeing that each one received proper credit for his work. He gave to his subordinates the same high loyalty which he expected from them, and which he rendered in turn to his employers. During his later years he was very active in various service organizations working with boys. Many men are finer and more useful citizens on account of the unpretentious example which he set.

[1] Read before the Association at Chicago, April 10, 1940.

[2] Secretary-treasurer of the Association.

Ralph Reed was a remarkable source of inspiration to the many geologists with whom he came in close contact. During the last twelve years of his life he constantly faced the spectre of Death, but it was during this period that he accomplished most of his important work. In spite of a burning desire to make the most of the limited time which he felt remained to him, he patiently devoted a large amount of his energy to the help of others, in order that the science of geology which he loved might be advanced to the highest possible degree. His own advancement was always a subordinate consideration, but it kept step inevitably with the rapid pace of his contributions. The stature of the man is measured by the monumental size of his carefully constructed works.

Many years ago we drew up a code of ethics for our professional conduct, to which we give at least lip service. These men needed no written code to guide them; they found within themselves the motivating forces for lives of real accomplishment. We honor them for their unselfishness, which, to them, was not incompatible with material success.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 7 (JULY, 1940), PP. 1162-1163

THIS ASSOCIATION[1]

HENRY A. LEY
San Antonio, Texas

Some men hold that ideas are weapons and that they have wrought all human advancement. This Association began as an idea. Twenty-five years have passed since a small group of geologists first gathered to lay the structural base of The American Association of Petroleum Geologists. A quarter-century old idea still possesses us. Under its spell we drive forward at accelerating rates as the expression of broad forces in fields of petroleum geology and business enterprise. We may shift our emphasis from time to time with the introduction of secondary ideas. We may concentrate our efforts for various purposes, but we return always to the purposes of that original idea whence we are sprung—petroleum geology.

We can be proud of what that small group of men did a quarter-century past. Their idea and its purposes have been consolidated into an institution that is a living part of the petroleum industry. Some of those men have returned to the earth whence they came. Our memories may be short and our recollections weak, but the handiwork of those men is an organic living record that permeates all of us.

In some respects the launching and growth of this Association were unique. Our founders gathered together at the dawn of a new science—petroleum geology. Our beginnings were not without opposition. The idea was neither proper nor acceptable to those weighted down with antiquated baggage. Notwithstanding, we have developed to a degree never before attained in the history of geology by recognizing and accepting a natural combination of the geological sciences and business enterprise. To some this combination may seem paradoxical, but we are living witnesses—3,300 strong—to the fusion of aggressive and cohesive scientific-economic forces and ideas of the same fibre. This Association has, undoubtedly, advanced beyond the fondest hopes of its founders to commanding position and respect. These are the specific consequences of propitious organization, circumstances of time, and sound constructive policies. We are the new concept in geology. Through us have come the great contributions of the past quarter-century to the general science of geology. We are, to-day, the front-line defenses of geology, concerned with geology, its scientific premises, and its utility in the national economy.

[1] Address of the president of The American Association of Petroleum Geologists, delivered at the twenty-fifth annual meeting of the Association, Stevens Hotel, Chicago, Illinois, April 10, 1940.

We need not resort to artificial reconstruction of the past to acquire respectability. We began as "rockhounds" and by diversification of activities are trending towards managerial or operating and advisory activities in the petroleum industry. There is no one pattern towards a career that we follow as a group or as individuals. Whereas our efforts once were limited to the mapping of surface folding, to-day emphasis is placed on initiative and originality and on judgment in matters both geological and economic. We are not academicians adhering to conventionalism and formalism. Neither are we cloistered scholars. We are not half buried in an abstract world, and half exposed to business. We are a part of business enterprise in action, engaged in applied aspects of geology. Therein lies, I believe, the secret of the growth and success of The American Association of Petroleum Geologists and its commanding position to-day.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 7 (JULY, 1940), PP. 1164-1203, 9 FIGS.

PALEOECOLOGICAL FACTORS CONTROLLING DISTRIBUTION AND MODE OF LIFE OF CRETACEOUS AMMONOIDS IN TEXAS AREA[1]

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ABSTRACT

This paper touches upon the growing importance of paleoecology. The classification of marine environments now in vogue with biologists is briefly reviewed and modified for geological and paleontological purposes. Two classifications are recognized. The habitat classification (planktonic, nectonic, necto-benthonic, benthonic) is used without reference to depth of water involved. It is concluded that most or all shelled cephalopods were mobile benthonic and necto-benthonic. The bathymetric classification refers to depth of bottom. Divisions recognized are: 1. littoral, 2. neritic (a. mud flat, b. reef, c. epineritic, d. infraneritic), 3. bathyal (a. epibathyal, b. infrabathyal), 4. abyssal.

It is suggested that the more obvious factors controlling ammonoid distribution may be interpreted in terms of morphology of shell, habits, and distribution of living cephalopods, associated fossil faunas, types of sediments, paleogeography, bottom, and factors of the water medium such as salinity, temperature, depth, oxygen content, waves, currents. Flotation of shells after death of the animal probably occurred, but was much less important as a factor of distribution than is commonly supposed.

On the basis of shell morphology the principal Cretaceous ammonoid groups recognized are: 1. smooth, involute, obese (*Phylloceras*), 2. smooth, evolute, obese (*Lytoceras*), 3. smooth, ovate (*Desmoceras*), 4. sculptured, ovate to quadrate, a. medium sculpture (*Dufrenoya*), b. robust sculpture (*Mortoniceras*), c. obese, spinose (*Neocardioceras*), 5. tenuous, involute, lightly sculptured (*Oxytropidoceras*), 6. tenuous, involute, smooth (*Engonoceras*), 7. uncoiled types (several subdivisions, *Turrilites, Hamites, et cetera.*)

It is noted that ammonoids do not occur in littoral, mud flat, or reef deposits, and are rare with *Orbitolina*, rudistids, and corals. Only the tenuous ammonoids (*Engonoceras, Oxytropidoceras*) are numerous with the abundant echinoids, oysters, and thick-shelled gastropods and pelecypods of the epineritic zone. Sculptured forms of great variety and abundance occur in sediments deposited in the infraneritic zone (estimated at depths of 20–100 fathoms). Smooth, ovate genera (*Desmoceras*) lived in the epibathyal zone at or just below 100 fathoms. Smooth, obese genera (*Phylloceras, Lytoceras* and related forms) are found to the exclusion of other fossils in sediments of the infrabathyl zone. The Texas Cretaceous seas were too shallow to attract the smooth obese genera.

Few invertebrate fossils have so captured the fancy of the naturalist, both professional and amateur, as the ammonites and nautiloids. Their strange shapes and great abundance over the extensive Mesozoic outcrops of Europe and the shores of the Mediterranean early brought their attention to civilized man and their dissimilarity to any other thing known to him naturally aroused his curiosity. The beginnings of stratigraphic geology are closely associated with regions of occurrence of ammonites and many stratigraphers have come to

[1] Address of the president of the Society of Economic Paleontologists and Mineralogists before the joint meeting of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists, at Chicago, April 10, 1940. Reprinted by permission from the *Journal of Paleontology*, Vol. 14, No. 4 (July, 1940).

[2] Department of Geology, Texas Christian University.

consider the ammonite the stratigraphic marker *par excellence*. The shells of these animals in fossil form have been the object of innumerable systematic and detailed studies so that today the most complex stratigraphic and phylogenetic classifications exist, and yet we are but little ahead of the ancients in our knowledge of the soft parts that occupied these shells in life, of their mode of life, or of the factors which controlled ammonoid distribution.

It is trite to call attention to the fact that such is the case because *Nautilus* is the only survivor of this great order, and that we do not know very much about either the habits of life or factors controlling the distribution of the four living species belonging to it. The vast suborder Ammonoidea has no living representatives and the soft parts of these animals have never been found sufficiently well preserved as fossils to give any very good idea of what they were like. We assume, and apparently with reason, that the ammonite body resembled the *Nautilus* and that when alive it breathed by four gills, but we do not know this to be a fact. With much less reason some of us postulate a hyponome for those ammonites whose shells are provided with the so-called hyponomic sinus. We leave that organ out of the ammonite's soft parts if the shell does not have such a sinus. The literature is replete with philosophical discussions of ammonite anatomy, even to the distinction between sexes. Some of these arguments are based on sound observation and reasoning; others would appear to be pure figments of the imagination. We do not even know that *Aptychi* and *Anaptychi* belonged to cephalopods at all, but we have good reason to think that they did. The reason for their incredible abundance where ammonites are rare or absent, and their absence where ammonites are abundant, is one of the most baffling puzzles in invertebrate paleontology. In spite of these gaps in our detailed knowledge of ammonite morphology we are reasonably safe in imagining a body not unlike that of the *Nâutilus*, the anatomy of which, thanks to Owen and others, is reasonably well known.

The life habits of fossil cephalopods have provided almost as fertile a field for philosophical discussion as has morphology. Here again the four living species of *Nautilus* are a point of departure. Unfortunately, the mode of life of the *Nautilus* is far less well known than its anatomy. Even if the mode of life of these four species were thoroughly known it would be folly to suppose that all the great and varied hosts of fossil nautiloids and ammonoids lived after the same pattern. Voluminous literature has accumulated on the subject and in it many points of view have been expressed.

The older students of cephalopod phylogeny, like Hyatt (1884),

were dominated by the theory of orthogenesis and the idea of racial senescence as expressed in the numerous and varied modifications of the cephalopod shell. Berry (1928) would have none of these ideas. According to his paper, "The keynote of evolution of the hosts of extinct cephalopods . . . is adaptation."

Hyatt's views, of course, are based upon the biologically outmoded idea of racial senescence. Berry's view is more in accord with modern biological concepts. This is a difficult, even treacherous subject and while recognizing the fundamental soundness of the adaptive idea, some paleontologists are old-fashioned enough to cling to many of Hyatt's well thought-out concepts.

It appears to the writer that one of the phases of cephalopod study that has been almost entirely neglected is that of their paleoecological relationships and the influence of such factors on their distribution. A. K. Miller and W. M. Furnish (1937) have recently published a stimulating discussion of the paleoecology of the Paleozoic cephalopods and there are numerous isolated ecological observations recorded in the literature, but no one has undertaken a serious paleoecological study of a Mesozoic area where a considerable variety of cephalopod material is found in some abundance. The Texas area would appear to be especially favorable for such a study. The rocks are in normal sequence, almost undisturbed, over enormous areas. Successive formations often show little variation for great distances and yet the vertical variations from formation to formation may be considerable so that many types of sediments are represented in the various formations. Fossils, including ammonites, are numerous in species and individuals. This paper purports to call attention to some of the possibilities in this field of research in the Texas Cretaceous.

Paleoecology is a science in which only the broadest outlines of procedure have been indicated and its possibilities of development would appear to extend without limit beyond the frontiers of our present knowledge. A worker in the field of marine paleoecology is at once aware of its complexity and of the special training and study required in it. Those who have not had thorough and extensive biological training, or who have not had the opportunity to observe the animals and plants of the seashore and of the shallow seas had best seek other fields in which to labor. Furthermore, paleoecology is so vast that the student must limit himself to some special phase of the subject, or to some area or group of animals. In this particular study, the factors of special interest, convenience and favorable conditions are the obvious limiting ones.

CLASSIFICATION OF MARINE ENVIRONMENTS

The fundamental classification of marine environments is complicated by the fact that it is designed primarily for the use of students of living forms. Its use is also made difficult because it is of necessity composed of two systems. Ordinarily, marine forms are classified as planktonic, nectonic,[3] or benthonic, depending on whether or not they float or swim passively, swim directionally through the waters at various depths, or remain on the bottom. This may be termed a *habitat* classification, and is used without reference to the depth of the waters involved.

The other classification is on the basis of bottom depth and may be termed a *bathymetric* classification referring to the depth of the bottom from the surface. From the shallowest to the deepest these are usually termed *littoral*, *neritic*, *bathyal*, and *abyssal*.

Each of these classifications is important and each is susceptible of innumerable subdivisions and refinements. Unfortunately, these terms are not standardized as to use so that each student finds it necessary to establish his own definitions, subdivisions and refinements. The writer's associate, W. G. Hewatt (1933), for example, in studying the benthonic animals of the sea, found a total lack of uniformity in definition of the littoral zone. According to his interpretation it lies between the "normal high-water line of the spring tides and the normal low-water line of the spring tides."

In this study the following habitat classification is followed.

1. *Plankton* is a term used for animals and plants which float, or swim passively at intermediate depths, or float at or near the surface in the seas.
2. *Necton* is a term which is used for organisms which swim directionally at intermediate depths.
3. *Necto-benthonic* organisms are those which hover over the bottom, periodically swimming near the bottom and then coming to crawl or to rest upon it.
4. *Benthonic* is used to designate bottom-living forms which may be (a) mobile benthonic, (b) sessile benthonic.

The following bathymetric classification is proposed for this study.

1. *Littoral* bottoms or deposits refer to those which existed or were formed along shore between high tide and low tide. They are identified by well known characteristics.
2. *Neritic* bottoms are those between low, low tide and the 80–100 fathom line. It is possible to recognize several subdivisions in this group in Texas as follows.
   a. *Mud flat* bottoms as defined here are somewhat more comprehensive than "mud flats" as commonly understood in most biological literature. As used here the term *mud flat* does not appear to apply to known modern seas of any considerable extent, but is believed applicable to certain ancient, extremely shallow, widespread and probably intermittent Cretaceous seas. The sediments are often muds or calcareous muds with occasional coquina

[3] The term *pelagic* is here comprehensively interpreted to include the necton and plankton, but there is the greatest disparity in the use of pelagic in biological literature.

limestones, all rich in marine fossils such as *Orbitolina*, large, thick-shelled gastropods and pelecypods. Sun cracks, animal tracks (dinosaurs of Cretaceous) are common. The water was probably reduced in salinity after heavy rains and it is probable that at intervals these bottoms approached or even reached the exposed mud flat stage over large areas. Ammonites are wanting.

b. *Zoögene* or reef bottoms, or deposits, are those formed by the remains of the usual reef-forming animals such as corals, and rudistids. Reef deposits are extremely shallow in depth.

c. *Epineritic* or shallow neritic bottoms are characterized by quantities of echinoids, and a great variety of large, thick-shelled pelecypods and gastropods. The presence of broad para-ripple marks and quantities of *Ostrea* and *Gryphaea* indicate that such bottoms did not exceed a depth of 20 fathoms. Certain types of ammonites are abundant. Others are wanting or rare.

d. *Infraneritic* deposits are composed of marls, shales, limestones, and arenaceous limestones. Their fauna is often rich and varied. Ammonites occur in profusion and variety. Algal remains and impressions are characteristic features indicating that neritic bottoms did not exceed a depth of 80–100 fathoms, or the maximum depth of abundant photosynthetic plants.

3. *Bathyal* bottoms in the continental and adjacent seas range from depths of 80–100 fathoms downward. It is possible to recognize two subdivisions as follows.

a. *Epibathyal* sediments were deposited on bottoms at the limit or just below the limit of green plants. The sediments are marls and limestones. The fauna consists predominantly of certain types of ammonites. Gastropods are rare or absent. Pelecypod associations are likewise poorly developed.

b. *Infrabathyal* sediments were deposited in the depths of the geosynclines of continental seas. The fossils are often preserved in pyrite and the fauna consists almost exclusively of diagnostic ammonites. Algal remains and gastropods are not found. The bathyal bottoms must have been below the 100-fathom depth, that is, well below the zone of light penetration sufficient to support green plants.

4. *Abyssal* deposits were presumably put down in the ocean depths. Since these are not subject to study they are of no importance here.

ANALYSIS OF POSSIBLE PALEOECOLOGICAL FACTORS CONTROLLING AMMONOID DISTRIBUTION AND MODE OF LIFE

There were probably a great many ecological factors affecting the distribution and manner of life of the ancient ammonoids of Texas and elsewhere. A preliminary analysis of these factors as far as they can at present be determined would appear to be fundamental to an understanding of the life habits of these ancient organisms.

The idea has prevailed generally that the shells of dead ammonoids floated widely over the oceans to become entombed in sediments far from their native haunts. As a consequence, it was thought that the present distribution of the fossils gave only a poor idea of the distribution of these forms when alive.

In the writer's judgment the flotation idea has been given an emphasis far in excess of its importance. Willey (1902, pp. 717, 719, 726) and Rogers (1908, p. 461) mention that shells of *Nautilus* have drifted ashore in certain localities. It should be remembered, however, that *Nautilus* is used as food by the natives and many of the shells mentioned may well have been empty ones cast back to the sea by the inhabitants. There can be little doubt that flotation of ammonoid

shells did occur, but shells which were transported to any considerable distance are likely to show the wear and tear incident to their voyage. There exists a number of ammonite localities in which a majority of the specimens are badly battered, thus indicating that they may have floated into a bay or eddy,[4] or were swept there by currents, tides, or storms, but these are the exceptions rather than the rule. Possibly some chance finds of single specimens represent individuals which floated away from their habitat after death. There is every indication that flotation was not an important factor in the distribution of the fossil shells, and the collector who finds himself in the presence of considerable numbers of ammonoids in the field can be reasonably certain that their original inhabitants lived on the site.

Many factors controlling ammonoid distribution will probably never be known, and it is certain that none is now perfectly known. It would appear, however, that the more obvious factors may be grouped as follows.

1. Factors suggested by the morphology of the ammonite shell
2. Factors controlling the life habits and distribution of the living Cephalopoda which may reasonably be expected to have influenced the fossil forms in similar manner
3. Factors indicated by fossil faunas associated with the ammonoids
4. Types of sediments in which ammonoids are most likely to occur, and their paleoecological significance
5. Ammonoid habitats and their observed relationship to paleogeography
6. Inferred and possible paleoecological effects of the water medium such as salinity, temperature, depth, oxygen, waves, currents, and bottom upon ammonoid life

FACTORS SUGGESTED BY THE MORPHOLOGY OF AMMONITE SHELLS

The shells of Cretaceous fossil Cephalopoda present an almost incredible variety of form and sculpture. The principal features which group themselves in different combinations to produce great variety are as follows: whorl section, rate of whorl growth, degree of coiling (whether involute or evolute) if coiled, shape of shell as a whole if coiled, costation (whether absent or present, or if present whether coarse or fine, curved or straight, *et cetera*), tuberculation, keeling, septal patterns, shell aperture, shell thickness.

The significance of none of these characters is particularly well understood and of some it can only be guessed. A few characters such as shell aperture and shell thickness are not readily observed in many specimens.

Shell aperture does not appear to affect very greatly the general shell shape but in certain instances may be suggestive of a mode of life. All other shell characters enumerated may be grouped to form the following principal shell types.

[4] E. Haug, *Traité de Geologie* (1920) lists a number of such localities where specimens were possibly accumulated in a given locality by flotation.

1. Smooth, involute, obese shells with circular or subcircular whorl sections as *Phylloceras* (Fig. 1)

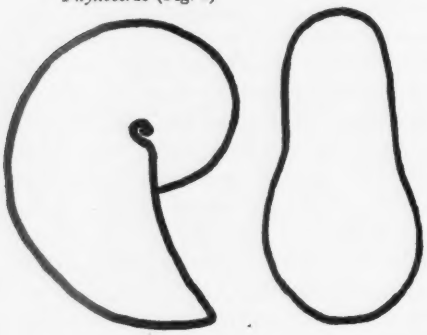

FIG. 1.—Outline drawings of *Phylloceras* illustrating shell form and sculpture of ammonites of group 1.

2. Smooth, evolute, obese shells with circular or subcircular whorl sections, such as *Lytoceras* (Fig. 2), *Tetragonites, Gaudryceras, Kossmattella, Jaubertella, Silesites*

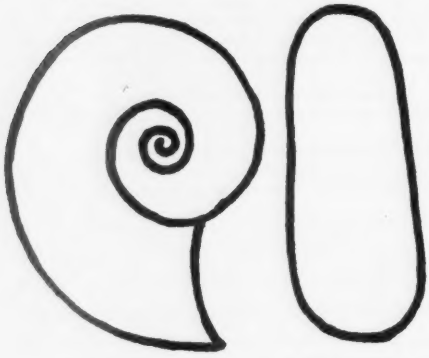

FIG. 2.—Outline drawings of *Lytoceras* illustrating shell form and sculpture of ammonites of group 2.

3. Smooth, moderately involute shells with ovate or subquadrate whorl sections, as *Desmoceras* (Fig. 3), *Uhligella, Beudanticeras, Latidorsella, Puzosia*

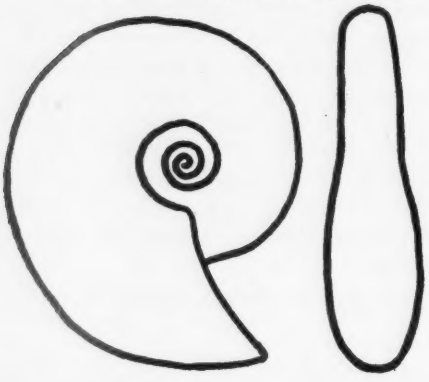

FIG. 3.—Outline drawings of *Desmoceras* illustrating shell form and sculpture of ammonites of group 3.

4. Sculptured shells with quadrate to ovate whorl section. This group includes the vast majority of Cretaceous ammonite shells of the Texas area. Involution, whorl section and sculpture show almost infinite variety. On the basis of sculpture these may be divided into three large groups
   a. Shells with fine to medium sculpture consisting of fine to medium costae, tubercles, keels, *et cetera*, as *Dufrenoya*, *Hoplites*, *Parahoplites*, *Hypacanthoplites* (Figs. 4 c, d), *Sonneratia*

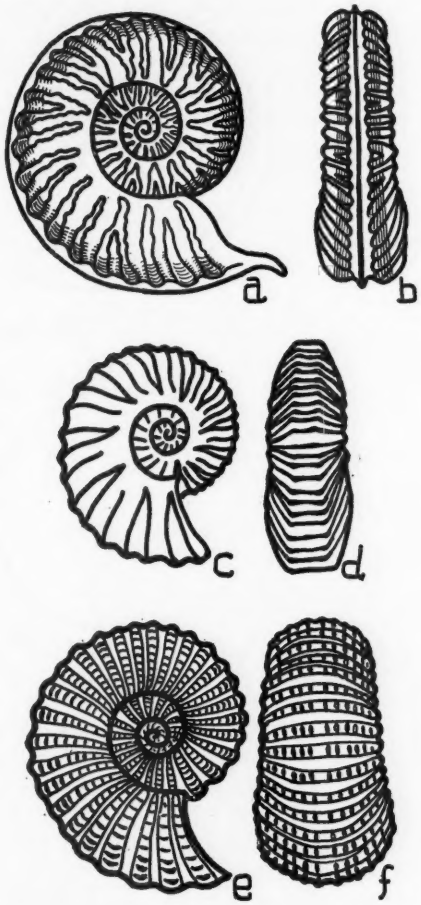

FIG. 4.—Outline drawings of *Mortoniceras* (a, b), *Hypacanthoplites* (c, d), and *Douvilleiceras* (e, f) illustrating shell form and sculpture of ammonites of group 4.

   b. Shells with robust sculpture consisting of coarse, widely spaced costae and strong, bullate tubercles. Costae and tubercles are often of irregular shape and spacing. Examples are *Mortoniceras* (Figs. 4 a, b), *Dipoloceras*, *Mantelliceras*, *Prohysteroceras*, *Acanthoceras*, *Douvilleiceras*, (Figs. 4 e, f), *Metoiceras*, *Barroisiceras*
   c. Obese, spinose shells represented by *Neocardioceras*

5. Tenuous, involute, finely costate, non-tuberculate, or only slightly tuberculate shells with thin whorl sections, often strongly keeled. *Oxytropidoceras* (Fig. 5), *Adkinsites, Manuaniceras, Venezoliceras* are examples of this type

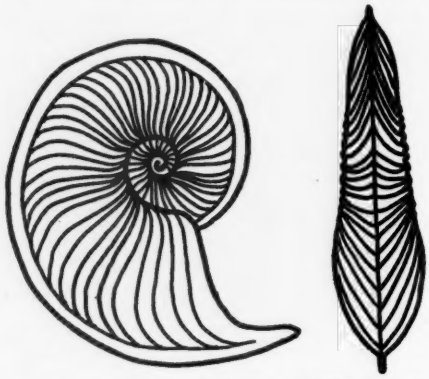

FIG. 5.—Outline drawings or *Oxytropidoceras* illustrating shell form and sculpture of ammonites of group 5.

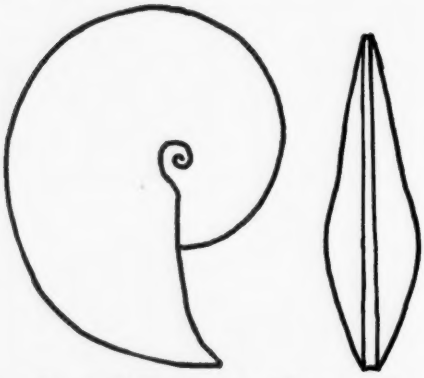

FIG. 6.—Outline drawings of *Engonoceras* illustrating shell form and sculpture of ammonites of group 6.

6. Tenuous, involute, smooth or with low, broad costae and tubercles. Whorl sections extremely thin, often truncate ventrally. *Engonoceras* (Fig. 6), *Knemiceras, Placenticeras, Sphenodiscus* are representatives of this group
7. Uncoiled or abnormally coiled forms in which a number of subtypes may be recognized
   a. Uncoiled, straightened, as *Baculites*
   b. Curved forms such as *Crioceras, Heliococeras, Allocrioceras, Exitelloceras*
   c. Partially uncoiled and hooked, as *Scaphites, Macroscaphites, Worthoceras, Hamites* (Fig. 7a)
   d. Spirally or irregularly coiled, represented by *Turrilites* (Fig. 7 b), *Bostrycoceras, Nostoceras, Nipponites*

This is, of course, a thoroughly artificial grouping arranged for the convenience of this type of study. It is a sort of morphological grouping based on shell structure, and it is interesting to consider these types in relation to their possible habitats and modes of life.

It has been suggested that the obese, smooth-bodied forms lived at some depth where their obese shells would be adapted to resist a relatively high pressure, whereas the tenuous forms living at shallow depths would not be required to resist any considerable pressures. According to the pressure idea, the intermediate forms with ovate to quadrate and subquadrate whorl sections, often with robust sculpture or ornamentation, would fall in between these two extremes.

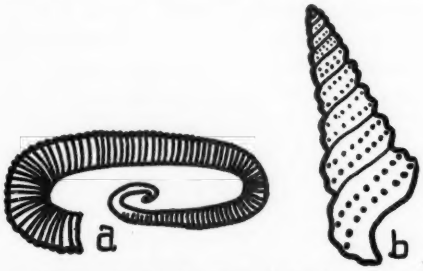

FIG. 7.—Outline drawings of *Hamites* (a) and *Turrilites* (b) illustrating shell form and sculpture of ammonoids of group 7.

The writer believes that, in general, obesity and smoothness of the ammonite shell together with thinness of shells indicate a depth habitat, and that tenuousness and relative smoothness and thick shells indicate shallowness of habitat, but the problem is really very complex. There are many exceptions as there are to any general rule. *Vascoceras*, for example, is obese, although it is not particularly smooth. It appears to have lived in relatively shallow water and is here classified with group 4b.

It is dangerous to assume a bathymetric distribution of the ammonites on the basis of shell form alone. Probably, internal and external shell pressure tended to maintain a balance just as in modern fishes with swim bladders. There should be, therefore, no particular reason for the added strength of the obese form. Secondly, the idea does not appear to be supported by shells of modern mollusks, obese and tenuous types of which live more or less indiscriminately in shallow or deep water. Actually, most living mollusks with thin cross section live in shallow water with their principal axis parallel to the direction of water movement in order to prevent as little resistance as possible to moving forces.

The thinking of investigators in this field has been strongly influenced by the idea that ammonoids must have filled all types of marine habitat. This is not necessarily true. It is entirely possible that the ammonoids we know were adapted to only certain types of habitats. Their place in other so-called life zones might well have been taken by other cephalopods which had no shells, and some of these might conceivably have been tetrabranchiates. In this connection it is well to remember that modern shelled mollusks do not usually float and seldom are found swimming widely among the necton.

In any discussion of the life habits of marine organisms, it is important to keep in mind the distinction between the habitat zones and the bathymetric zones just emphasized.

To state this point in another way: if shell modification indicates depth of ammonite habitat, should it be assumed that some species were planktonic, others nectonic, and still others benthonic; or were all or most of the ammonites of Mesozoic time benthonic or nectobenthonic, so that depth habitat corresponds to the bathymetric zones?

In this connection it is interesting to examine Berry's (1928) diagram in which he postulates "adaptational modifications of the Cephalopoda with external shells." He emphasizes the significance of the supposedly gas-filled chambers of the shells as agencies of bouyancy for the animal and distinguishes between suspended pelagic floaters, nectonic swimmers, and benthonic crawlers, pointing out the various shell adaptations favorable to each type.

Berry's arguments are put forward with considerable logic, and yet the writer does not believe that facts of ammonite habitat, ecology and distribution support his ideas conclusively. Berry calls attention to the contracted aperture of certain cephalopods with depressed whorls and suggests that this character was an adaptation to prevent the animal being dislodged from its shell, as the latter was dragged across the bottom. This is a character, however, of adult shells and, if of importance in preventing such dislodging accidents, there should be considerable evidence in young fossil shells to indicate that their soft parts had been wrenched from them. Such is not the case. Furthermore, contracted apertures are characteristic of many ammonite species, some of which have depressed whorls, but many of which have compressed whorls. The writer has a single specimen in which the soft parts were evidently partially dislodged from the shell by a blow on what was then the posterior margin of the shell. The animal was partially rotated in its shell, became reattached and continued to grow for some time afterward. The ventral lobe of the suture lies on the

ventro-lateral area of the shell. Incidentally, configuration of the shell grown after the accident was entirely normal. There is every indication that ammonites were held in their shells by strong muscular and other fleshy attachments. Reduced apertures of some sort are rather characteristic of most adult Cretaceous ammonites that the writer has been able to observe.

Other apertural characters which have given rise to much speculation are the so-called hyponomic sinus indenting the lip of many cephalopod shells, the greatly extended and often recurved ventral rostrum of other shells, and the various attitudes that the aperture may assume.

It has been common practice to correlate the hyponomic sinus with the presence of an efficient hyponomic funnel which expelled water forward, thus serving to propel the animal backward after the manner of the modern squid. By correlative reasoning it has been assumed cephalopods without this sinus were not provided with a functional hyponomic funnel, probably did not have any other swimming organ and were, therefore, either crawlers or floaters.

Many Albian ammonites, notably the mortoniceratids and the oxytropidoceratids, had strong keels prolonged into curved or recurved rostra. Many lines of evidence indicate that all of these forms swam, at least moderately. This does not mean, however, that such types swam far and wide. Probably, even the good swimmers spent much of their time crawling on or hovering over the bottom and seldom swam far from it. From a purely mechanical point of view there is no real reason why a rostrum should greatly interfere with a properly placed hyponomic funnel. Obviously the idea held by Hyatt (1894) and others that a shell devoid of a hyponomic sinus could not have harbored an ammonite capable of swimming needs drastic revision.

The writer can not but feel that the sculpture of certain types of ammonites may suggest something of the nature of their habitat and mode of life. *Oxytropidoceras* is a superb example of streamlining of an ammonite shell. Its ribs are small, steep anteriorly, gently sloping posteriorly and are curved far forward to merge with the sharp keel, but it is provided with a long slightly recurved rostrum which according to some would exclude any possibility of swimming. The shell form of *Oxytropidoceras* suggests a rather efficient backward swimmer. Other types of ammonites such as *Mortoniceras* and *Acanthoceras* do not exhibit this streamlined effect at all. They were probably awkward swimmers, although their predominant type of locomotion must have been crawling.

A few ammonites, such as *Neocardioceras*, were provided with long, inflexible spines, often longer than the diameter of the shells. *Neocardioceras* is an extremely globose shell. It is difficult to see how such an ammonite could have enjoyed any considerable freedom of movement of any kind.

Berry's diagram suggests a benthonic crawling existence for spirally coiled forms such as *Turrilites* and for irregularly coiled forms such as *Nipponites*, and the shells of these animals certainly suggest such an existence. It is not, however, a foregone conclusion that they were incapable of locomotion by the usual method of the hyponomic funnel. To the same author shell forms exhibited by such genera as *Macroscaphites*, *Scaphites*, and *Heteroceras* suggest a sort of immobile and suspended floating, or planktonic existence, but at the same time he calls attention to "how cautiously shell form must be used in predicating locomotive ability." The writer is entirely in accord with this cautious interpretation. The form of shell of *Macroscaphites* is indeed suggestive of a pelagic, non-swimming existence, but aside from the fact that mollusks provided with shells are very rarely pelagic, factors of distribution and associated animals are definitely opposed to such an existence for *Macroscaphites* and similar types. Rather a nectobenthonic crawling and swimming habit of limited extent is suggested for them.

In the complications of septal walls and resulting sutures, and in the wide variety of keeling found in many cephalopod shells the writer is unable to find a single suggestion of reflected surroundings. These structures are, no doubt, of fundamental significance, but all explanations of them so far advanced are little more than guesses.

LIVING CEPHALOPODS AND POSSIBLE ECOLOGICAL FACTORS WHICH THEY INDICATE FOR FOSSIL FORMS

Living Cephalopoda show almost infinite variety of body form and habit of life and yet there are considerable numbers of characteristics common to the entire group or at least to very large parts of it. Cephalopods range in size from minute forms, to the giant squids which may reach an over-all length of 52 feet (*Architeuthis princeps* or Atlantic squid). Most modern Cephalopoda have no shells at all or only vestigial ones, but a few such as *Nautilus* are enclosed in shells of well known pattern. Their food is preponderantly, although not exclusively, composed of Crustacea and small fishes. This single factor is an important one in limiting the distribution of modern cephalopods. Since this is a rather uniform factor we may reasonably assume that it had a similar limiting effect upon ancient forms such as the ammo-

nites. Whales, sharks, and other large marine carnivora are their mortal enemies. The modern cephalopod in the vicinity of a whale or shark must have a much better chance of survival if he is on the bottom or if near enough to the bottom that he may get there quickly. The same was probably true for the ancient ammonites.

It is generally assumed that *Nautilus* among the living cephalopods most nearly parallels the ancient ammonites in habits and mode of life as well as in structure. Willey (1902, p. 698), to whose work reference is most frequently made concerning the living conditions suitable for *Nautilus*, simply says that traps are set at depths of 30–70 fathoms. His text, however, suggests that *Nautilus* may be found from depths of a few fathoms to indefinite depths. Julia Rogers (1908) states that it is found most abundantly at depths around 300 fathoms, but her work is not satisfactorily documented. Most texts and other papers which have discussed the modern *Nautilus* mention that it lives in relatively shallow water and yet very few actual data on this subject have been assembled. From the biological point of view which takes into consideration the entire ocean, 300 fathoms is shallow. From the point of view of the geologist who has available for study only the sediments of the shallow epicontinental seas, 300 fathoms is decidedly deep.

According to all investigators *Nautilus* lives gregariously, swimming near or crawling on the bottom and the speed of movement is inconsiderable. Specimens have been reported floating at the surface, but according to most authorities such rare individuals are either sick or dead.

Sexes in all cephalopods are separate. In many groups sexual dimorphism is extremely pronounced. For example in *Argonauta* the females may be fifteen times as large as the males. The females also have shells and great enlargement of the dorsal arms which characters are not found in the males. It has been demonstrated that in most Cephalopoda the males are much less numerous than the females (hyperpolygynous). In *Nautilus*, however, sexual dimorphism is extremely slight and in *Nautilus pompilius* males seem to be more numerous than females (hyperpolyandrous).

Students of fossil cephalopods have been able to learn little if anything concerning the differences in sex in fossil ammonites and nautiloids. A few investigators have thought they might be able to identify sexes in certain ammonite species, but such findings proved difficult or impossible of demonstration. Markedly small and large sizes, obesity and thinness of marked extremes, and the like, in given species may mean that one group is male and the other female (in

Nautilus the aperture is more flared in males than in females), but there appears to be no real way of knowing.

The sense organs, particularly those of equilibrium and of sight are well developed. Sight is an important factor in the life of many modern cephalopods and was probably no less important in the lives of ancient types.

The modern Cephalopoda are exclusively marine animals. No authentic record exists of their habitual occupation of either fresh or brackish waters. They are occasionally carried by storms or currents into estuaries or other brackish-water areas but can not tolerate even slightly reduced salinity. There is every good reason to believe that such has always been the case with the cephalopods. Modern cephalopods can, on the other hand, tolerate saline conditions somewhat above normal, since they have been known to live in the Suez Canal where salinity is relatively high.

Many genera and a number of species are cosmopolitan in their distribution. That certain ancient ammonites were similar to them in this respect appears to be well established. Some species have marked preference for the warm waters of tropical and sub-tropical areas whereas others prefer the colder waters. Thus the oigopsids *Cranchia scabra* and *Pyrgopsis pacificus* are found around the world in tropical and sub-tropical waters, but are not found in the higher latitudes.

A few cephalopods such as the larger decapods spend their lives swimming through the oceans at various depths. A few such as *Crancia* (Oigopsida) are planktonic and float with the ocean currents. Some few species, notably of the Oigopsida, dwell at considerable depths: *Spirula*, 1,000 fathoms; *Cranchia* and *Bathyteuthis*, 1,700; *Histiopsis*, 2,000; *Colliteuthis*, 2,200; *Cheiroteuthis*, 2,600 (Lankester, 1906). A number are luminescent. A very few such as *Sepiola* and *Rossia* are fossorial.

These habits of life are the exceptions rather than the rule. The vast majority of all modern Cephalopoda live an active and gregarious existence in relatively shallow water. Here they remain for the most part quite close to the bottom, crawling or resting on it, hovering or swimming just off of it. Except for *Nautilus* and a few others, they are, of course, without shells.

There seems to be every good reason to believe that the ancient ammonites, and probably the ancient nautiloids, of the Cretaceous of Texas lived after the fashion of most modern cephalopods: in relatively shallow water, probably for the most part in droves, crawling upon, or hovering and swimming just above, the bottom in areas where food, in the form of Crustacea and small fishes, was abundant.

There is no evidence that they ever lived in fresh or even brackish water. There may have been forms without shells which were planktonic floaters but evidence will be presented to show that none of the shelled species which have thus far been postulated as floaters was such in reality. So far as the writer is aware, there is no evidence whatsoever to indicate that any ammonite was ever a burrower. There may have been ammonite inhabitants of the deep seas, but sediments of the ancient ocean depths are not known to us.

Of the eggs and developing young of most Cephalopoda, very little, unfortunately, is known. The eggs of those whose breeding habits are known are normally laid inshore, singly or in clusters, and are usually fastened to the bottom in some way. The eggs are distinctive on account of their large quantities of yolk. Brooding over the eggs by the females takes place in some species. A thorough study of the embryology and behavior of the young of the modern Cephalopoda, particularly *Nautilus*, might be of inestimable value in deciphering the life secrets and relationships of the ancient cephalopods, but these data are yet to be assembled.

Cephalopod eggs, whether single or in clusters, are united in a continuous cellular follicle. Copulation takes place, usually by a hectocotylised arm which may be caducous. A few such as *Argonauta* are viviparous, but in most species, the eggs are deposited after fertilization and the young are not nurtured. The number of eggs laid is extremely variable (Loligo, 40,000). The larvae of cephalopods are not trocospheric, but the young hatch out to resemble the adults very closely. The period of incubation is variable, but considerably longer than in other mollusks. The habits of the larvae are little known, and in most species do not appear to be markedly different from the adult. The marine larvae of temperate seas are relatively intolerant of temperature rises, thus excluding the cephalopods from shallow waters which may suddenly become warm. There is little doubt that the larvae of the ancient ammonites were similarly sensitive to temperature changes, and this factor can conceivably have affected their distribution.

FACTORS INDICATED BY FOSSIL FAUNAS ASSOCIATED WITH THE AMMONOIDEA

Miller and Furnish (1937) and others have called attention to the possibility of deriving considerable information concerning the paleoecology of a group of organisms from a study of the associated fossils. In the writer's opinion the value of this type of attack in studying the paleoecology of a group such as the cephalopods can not be overemphasized. It is a method of study, however, which encounters

numerous difficulties and which, if not employed with the greatest caution, may easily lead to serious inaccuracies. For example, it may be that a given ammonite fauna is limited to a definite stratum of only a few inches thickness in a formation where other fossils are found throughout. In such a case it is important to delimit the faunas associated with the ammonites to those species actually found in the ammonite-bearing ledge. For purposes of paleoecology, it is necessary to re-collect in most localities with the idea of definite associations in mind. Since this has not been the general practice, published lists of faunas for many formations are useless in paleoecological studies.

It is well known that Cephalopoda do not commonly occur in association with certain types of marine fossils, and observations calling attention to this discrepancy in their occurrence are abundantly recorded in the literature. Foerste (1936) has stated that where early Paleozoic cephalopods are abundant the mobile gastropods are likely to be abundant, but the sedentary brachiopods, corals, and bryozoans will probably not be found in quantities. A. K. Miller and Furnish (1937), however, have observed that "in the Upper Ordovician of the northwestern United States the remains of nautiloids, mobile gastropods, and corals very commonly occur together," and call attention to the fact that such an association is particularly noticeable in near-shore deposits such as the Lander sandstone of the Bighorn formation. These writers also make the statement that "in the Early Paleozoic deposits cephalopods are commonly found associated with heavy-shelled benthonic animals, indicating that the entire fauna lived in relatively shallow water." These statements refer, of course, to older Paleozoic Nautili. The Cretaceous cephalopods, and particularly the ammonites, are infinitely more variable than the Paleozoic nautiloids, and individual species were apparently much more sensitive to their environment.

It is not a new observation to point out that in Texas, ammonites are rarely found associated with the remains of reef-building animals of any kind. Only accidental finds of ammonites associated with rudistids, reef-building corals or large Foraminifera such as *Orbitolina* have ever been recorded,[5] and ammonites did not appear to favor the brachiopod habitat. Likewise, most ammonites are not found abundantly along with plentiful representatives of the echinoderm phylum, although certain ammonoid species (notably flat, thin, little-sculptured species) may be numerous. Incidentally, F. B. Plummer, R. C. Moore, and the writer in collecting ammonoids and crinoids in the

[5] The writer understands that abundant ammonites and *Orbitolina* have been found closely associated in Cretaceous rocks in Arabia.

Texas Pennsylvanian have learned to look for these two types of fossils in different stratigraphic units. Pennsylvanian ammonoids seldom are found with fusulinids.

The Glen Rose formation crops out over enormous areas of Texas and parts of Arkansas. All of its extensive exposures are richly fossiliferous. Rudistids such as *Monopleura*, *Toucasia*, and others are numerous at certain levels. *Orbitolina* is abundant but restricted to certain levels. Oysters of many genera and species are well represented and they occur as fossil oyster beds with less abundant specimens scattered throughout the formation. So far as the writer is aware, no cephalopod has ever been found in these Glen Rose rudistid, or *Orbitolina* beds, and they are rare in oyster beds. Most of the Glen Rose clays, shales and limestones carry numerous specimens of many species of large, thick-shelled pelecypods and gastropods, and some levels are rich in echinoids, Bryozoa and reef-forming corals. Throughout these strata, except in West Texas where conditions are different, cephalopods, with the exception of the thin-bodied, little-ornate type such as *Knemiceras*, are of accidental occurrence. Most cephalopods apparently could not endure the environment favored by such types as the rudistids, corals, Bryozoa, *Orbitolina*, *Ostrea*, and the large thick-shelled pelecypods and gastropods. It is not known if these types were in themselves obnoxious to the ammonites. More probably, such factors as the shallowness of the water, or the variability in salinity, or the extremes of temperature of such waters were not favorable to them or to their eggs and larvae.

In extreme West Texas in the center of the old geosynclinal area now occupied by the Quitman Mountains and extending southeastward into Mexico there are thick Glen Rose strata in which rudistids, corals, orbitolinas, and oyster beds are not found, and echinoderms and large thick-shelled gastropods and pelecypods are rare. In these strata a rich cephalopod fauna has been found. All the species described belong to what, in this study, is called the sculptured type (group 4) with quadrate to ovate whorl sections such as *Dufrenoya*, *Hoplites*, *Parahoplites*, *Sonneratia*, *Douvilleiceras*, *Trinitoceras*, *Hypacanthoplites*. Thin-bodied, little-ornate types such as *Knemiceras*, *Pseudosaynella*, and the nautiloid *Vorticoceras* have not been found in these strata.

The Fredericksburg group of strata (middle Albian) in Texas is remarkably uniform over wide areas. The group typically comprises the Walnut shell beds (*Exogyra* and *Gryphaea*); the Comanche Peak strata composed of shales, clays and white nodular limestones; the Edwards limestone and the Kiamichi clays. North of the Brazos

River the combined Comanche Peak and Edwards strata constitute the Goodland formation.

The Walnut shell beds yield occasional ammonites, but so far as the writer is aware, all the specimens that have ever been found in these strata are of the thin-bodied, little-ornate type belonging to the genera *Oxytropidoceras* and *Engonoceras*. Specimens of these genera are often found incorporated in the broadly rippled shell beds with many shells attached.

In the Comanche Peak clays, shales and nodular limestones, ammonites are almost unbelievably abundant, but with the exception of a *Hamites*, a few specimens of *Dipoloceras* and two or three as yet unidentified fragments, the many Comanche Peak specimens all belong to the thin-bodied, lightly sculptured genera such as *Engonoceras*, *Oxytropidoceras*, *Venezoliceras*. The associated fossils are incredible numbers of echinoids, oysters and oyster beds, corals, worms, and a bewildering array of large and small thick-shelled gastropods and pelecypods.

At three localities in the Goodland the writer has taken at random three areas of 144 square feet each and has counted 6, 7, and 14 specimens of tenuous ammonites in them. No other cephalopods were found. Each of the squares yielded more than 100 echinoids, more than 100 large, thick-shelled gastropods (*Natica*, *Tylostoma*, *Nerinea*) and pelecypods (*Cyprimeria*, *Protocardia*, *Trigonia*, *Pholadomya*), several solitary corals, oysters, and incredible numbers of *Gryphaea*. In one *Gryphaea* shell bed 3 inches thick, twelve large ammonites were counted in a distance of 15 feet. Numerous *Gryphaea* and *Ostrea* adhered to the cephalopods.

Assuming that these Cretaceous organisms lived at depths inhabited by corresponding modern types the ancient Albian seas of Texas which the tenuous ammonites found so hospitable, must have been, for the most part, less than 20 fathoms in depth.

The Edwards is essentially a reef limestone[6] composed in many places of rudistids (*Monopleura*, *Taucasia*, *Caprina*, *Caprinula*, *Biradiolites*), corals, large and thick-shelled gastropods and pelecypods and other bizarre types. There are no ammonites.

The Kiamichi is a clay with a few thin beds of yellow nodular limestone and many thin beds of sandy flagstones. The fauna is not especially varied. The principal elements are *Gryphaea* and other oysters, *Trigonia*, *Arctica*, *Protocardia*, *Inoceramus*, and a few other large clams and some gastropods. Thin-bodied, lightly sculptured

[6] "Bioherm" and related terms proposed by Cumings (1932) are lacking in the specific meaning required for use here.

ammonites such as *Oxytropidoceras*, *Manuaniceras*, and *Adkinsites* are abundant. In the uppermost levels a few specimens of *Elobiceras* (quadrate whorls with robust sculpture) and possibly related genera have been collected.

The middle Albian of other regions than Texas has yielded some of the richest and most varied ammonite faunas known from any strata, and it is therefore singular that these strata in Texas should have yielded almost exclusively the tenuous, smooth and little-sculptured forms. It would appear that an environment favored by oysters, echinoids and large, thick-shelled pelecypods and gastropods was unfavorable to practically all Albian ammonites except the tenuous, little-ornamented types. The reef habitat was not favorable at all to middle Albian ammonites.

The Washita (Vraconnian, upper Albian) group of sediments in Texas is extremely variable and its ammonite fauna, much in need of monographic study, is especially interesting. In the typical North Texas area the succession of formations recognized is as follows: Duck Creek, Fort Worth, Denton, Weno, Pawpaw, Main Street, Grayson.

The lower half of the Duck Creek is a veritable bonanza of ammonites and the dominant type is the large, smooth, moderately evolute shell with ovate to subquadrate whorl section exemplified by *Desmoceras*, *Uhligella*, *et cetera*. Around Fort Worth thousands of these shells have been collected for rock gardens, fences, fireplaces, and posts in the parks. The writer knows of small streams where one may walk for several yards stepping from one to another of these large specimens. Associated with these smooth, ovate-whorled forms are numerous other species belonging principally to quadrate-whorled robustly sculptured types such as *Mortoniceras*, *Prohysteroceras*, *Hamites*. Most of these species are large. Fossils, other than ammonites, are not numerous in the lower Duck Creek. *Inoceramus* is frequent, an occasional echinoid is found, but gastropods are rare and small in size, and the limited numbers of pelecypods found are small and thin-shelled. Scarcity of algal remains and the rarity of gastropods suggest that these strata may have been deposited at or possibly below the limit of green plants, that is, below a depth of 80–100 fathoms.

In the upper Duck Creek marls the fauna is more varied. Ammonites are still predominant at most levels, but the variety is considerable and the smooth forms with ovate whorl sections such as *Desmoceras* are not the principal element of the fauna. In Tarrant County the brachiopod *Kingena wacoensis* occurs in great profusion through a narrow thickness. Ammonites are rare or absent in this

zone. At one locality in Fort Worth the small echinoid *Goniophorus scotti* Lambert is found in great numbers, but occurs only in a narrow radius. Other echinoids, however, are not uncommon in the upper Duck Creek over wide areas. *Gryphaea* occurs in some abundance and there are several other species of pelecypods and a few species of gastropods. For the most part these are relatively small and thin-shelled types, and they are not numerous either in species or individuals.

The cephalopods are represented principally by several species of *Mortoniceras* and *Prohysteroceras*, but *Desmoceras* and *Uhligella* occur sparingly. *Scaphites*, *Worthoceras*, *Hamites* and *Crioceras* are important elements of the fauna.

An interesting feature of the upper Duck Creek fossils is the preservation of many of them in pyrite and marcasite. The ammonites, of course, are particularly adapted to this type of preservation, but many small gastropods, pelecypods and even echinoids are also preserved in this manner. The pyrite ammonites are all small, and were once described by the writer (1924) as a dwarfed fauna. Many of them are indeed small species as indicated by adult specimens of *Worthoceras* and *Scaphites*, but it is probable that many of them are the preserved inner whorls of large specimens.

In connection with this "pyrite fauna" it is worthy of note that in the marly formations in the centers of deep ancient geosynclines the faunas are composed almost exclusively of the smooth, obese types of ammonites, often preserved as pyrite pseudomorphs. The writer, however, has examined a number of these faunas from such regions as the Alps and has noted certain differences in their character. In addition to being predominantly smooth, obese forms, the Alpine specimens are larger than the Texas pyrite forms and obviously are the preserved inner whorls of relatively large individuals. The Texas pyrite faunas such as are found in the upper Duck Creek, Denton, Pawpaw, and Grayson do not contain the smooth, obese ammonites, but are composed largely of mortoniceratids, scaphitids, desmoceratids, turrilitids, hamitids, *et cetera*, and even engonoceratids. Many of them are obviously dwarfed, and the fauna contains many elements besides ammonites, such as echinoids and considerable varieties of gastropods and pelecypods.

The ammonites of the Fort Worth formation are predominantly of the types characterized by robust sculpture, and quadrate to subquadrate whorls. They are for the most part mortoniceratids. Associated with them are abundant and varied pelecypods and gastropods, some of which are moderately large and thick-shelled. Echinoids,

though not abundant as measured by the standard of the Goodland, are plentiful. Large oysters and worm tubes are also common. A notable feature of the Fort Worth is that many of its limestone ledges are veritable masses of supposed algal material ordinarily referred to as "fucoids," but the specimens are not really determinable.

The Denton is a marly clay, topped by a *Gryphaea* and oyster shell bed. Ammonites are not abundant, but on the Red River where the formation is thickest they are sparingly found in the lower clays. They are predominantly mortoniceratids and are preserved as pyrite pseudomorphs. Small crustaceans, *Gryphaea* and *Ostrea*, are in closely associated strata.

The Weno ammonites are mainly mortoniceratids and are reasonably abundant. They are accompanied by a varied fauna of echinoderms, the large Foraminifera, *Haplostiche*, and numerous pelecypods and gastropods. The large, thick-shelled pelecypods and gastropods, however, are not found or are rare.

The Pawpaw is best developed near Fort Worth and contains a pyrite fauna of striking variety. Turrilitids, mortoniceratids, scaphitids, hamitids, and engonoceratids are abundant. A rich fauna of small echinoids, small gastropods and pelecypods, shark teeth and vertebrae, and crustacean parts accompany these cephalopods. Algal remains are a prominent part of calcareous flagstone layers.

The cephalopod remains in the Main Street limestone are almost exclusively turrilitids of large size and the large *Nautilus texanus* which is found sparingly throughout the Washita group of sediments. Other cephalopods of robust sculpture and quadrate-whorl section are occasionally found. The other fauna is not conspicuous, but echnoids, oysters, pelecypods, and gastropods are found.

The Grayson presents another zone of pyrite faunas and their constitution is similar to that of the Pawpaw faunas. Turrilitids, scaphitids, engonoceratids, and the mantelliceratids are the predominant cephalopods. Other fossils are small gastropods and pelecypods, and echinoids. Toward the top of the formation the strata become more calcareous; oysters, such as *Gryphaea*, are more numerous; pectens of large size, large pelecypods, gastropods, and echinoids are common. The only ammonites found in any abundance in these upper strata are *Engonoceras* (tenuous, little-sculptured), *Stoliczkaia* (robustly sculptured, subquadrate whorl section), and *Turrilites*.

The Woodbine sand was deposited probably as a river delta, and along the outcrop is composed of non-marine and brackish-water deposits. Land plant fossils are found at some levels, and there are oc-

casional strata bearing brackish-water mollusks. No cephalopods have been found in the Woodbine.[7]

Over much of Texas the Eagle Ford group and its equivalents reach thicknesses of 300–500 feet. Ammonites occur in considerable abundance at several levels and sporadically throughout the group. The strata have also yielded a rich fauna of other mollusks, Foraminifera and Ostracoda, but these fossils have not been adequately collected with a view to determining their association with the ammonites within definite stratigraphic limits. It is, therefore, difficult to speak with any degree of accuracy concerning the species which are associated intimately with the ammonites. There are, however, at least three zones where ammonites are relatively abundant and in which, thanks to W. L. Moreman (1927), the associated faunas are known with some accuracy.

The lowest of the zones is the so-called *Acanthoceras* zone. In Tarrant and neighboring counties this zone is especially well developed and appears to extend southward as far as Bell County (Adkins, 1930) and northward to the Red River. In the section it lies in the calcareous marls and clays immediately above the massive sandstones and oyster beds ordinarily known as the Lewisville beds of the Woodbine, but believed by many to be of Eagle Ford age. To the south in Johnson County and beyond, specimens are sometimes found in the flaggy sandstones at the base of the marls. Acanthoceratids (quadrate whorls, robust sculpture) are the abundant ammonites in this zone but an engonoceratid (*Epengonoceras dumbli*) is occasionally found. In this ammonite zone the large and beautiful *Arca tramitensis* and a small undescribed *Exogyra* occur in great abundance. Just under the zone is a bed in which shark teeth of the so-called "pavement" variety abound. Other pelecypods and gastropods are found in the zone, but they are neither varied not abundant.

The next zone of abundant ammonites occurs near the middle of the Eagle Ford group in dark to black laminated shales with iron-claystone concretions. The ammonite fauna is prolific and varied. The dominant types are the robustly sculptured forms with quadrate whorls represented by many species of *Metoicoceras* (group 4b), thin-bodied involute smooth forms represented by several species of *Placenticeras* and *Protengonoceras* (group 6), obese, irregularly costate, and strongly spinose forms represented by *Neocardioceras* (group 4c) and a great variety of uncoiled and abnormally coiled forms represented by the straightened *Baculites* (group 7a), the curved and

[7] *Acanthoceras wintoni* Adkins (*Univ. Texas Bull. 2838*, p. 244), reported from the Woodbine, is certainly from the Eagle Ford.

slightly spiral *Exitelloceras* (group 7b) and the partially uncoiled and hooked types represented by several species of scaphitids (group 7c). The preservation of these fossils is often remarkable.

The fauna associated with the middle Eagle Ford ammonoids is not particularly striking. *Inoceramus*, represented by several species, all of relatively small size, is perhaps the most noticeable molluscan element. A few other pelecypods and gastropods are found in considerable abundance preserved in the concretions with the cephalopods, but they have no particularly definitive characteristics. Remains of small and large fishes and sharks are plentiful, and a few remarkably well preserved specimens of fish have been found. These beds have also yielded the teeth, vertebrae, and even complete skeletons of the marine reptile *Mososaurus*.

Some hundred feet below the top of the Eagle Ford there are thin beds of flaggy, arenaceous limestones which crop out to form a low scarp on the otherwise flat to slightly rolling Eagle Ford terrain. In places these strata carry abundant ammonoids, but elsewhere appear to be barren. The principal types are prionotropids, forms with quadrate whorls, extremely robust sculpture (group 4b), but genera of other similar groups and uncoiled forms also occur. The fauna is in need of adequate analysis and description. Associated with these ammonites are incredible numbers of small to medium-sized *Inoceramus*, gastropods, scaphopods, limpet-like shells, and quantitites of fish remains such as scales and teeth, and the bones of *Mososaurus*.

It is notable that nautiloids have not been found in the Eagle Ford. A few heavy-bodied ammonites of the pachydiscid type (group 3) have been collected in the strata, but they are definitely rare.

The Austin chalk carries a rich fauna, but unfortunately it has been little studied. The principal cephalopods are the globose nautiloids, *Eutrephoceras dekayi* and related species, ammonites of the group of *Ammonites texanus* and *Barroisiceras* (robust sculpture, quadrate whorls, group 4b), *Placenticeras* (group 6) *Pachydiscus*, and *Parapuzosia* (group 3). *Baculites* (group 7a) and *Scaphites* are also well represented. *Pachydiscus* and *Parapuzosia* are not numerous in the Austin chalk except in southwest Texas near the Rio Grande where *Parapuzosia* is represented by the giant species *P. americana* and *P. bösei*. The principal associates of the Austin chalk ammonites seem to have been incredible numbers of *Inoceramus* belonging to many large and small species. Large specimens of rudistids belonging to *Durania* and related genera are also found in the chalk, but they are not in reefs, and whether or not the specimens occur in the same strata with the ammonites is not known. Other mollusks and con-

siderable numbers of echinoids are also found, but the degree of their association with the cephalopods is yet to be worked out.

The cephalopod fauna of the Taylor, as yet poorly known, does not appear to present ecological features differing appreciably from those of the Austin chalk. The principal types are placenticeratids (tenuous, smooth, group 6), *Prionocyclus* (robust sculpture, quadrate whorls, group 4b), *Baculites* (group 7a), and *Scaphites* (group 7c). In South Texas in Medina and neighboring counties the Taylor has yielded pachydiscids, *Puzosia* and *Parapuzosia* (group 3). In all cases *Inoceramus* is abundantly associated with these ammonites, but other associated fossils are as yet poorly known.

In the Navarro and its equivalents ammonoids are often abundant at certain levels. The dominant genera are perhaps *Sphenodiscus* and a relative *Coahuilites* (tenuous, smooth, group 6). Along the Rio Grande, 15–18 miles below Eagle Pass in Texas and in Mexico, the writer has collected species of these genera in unbelievable numbers, and they are almost the only cephalopods to be found in the strata. In close association with them are rich faunas composed of oysters and a great variety of large pelecypods and gastropods.

In the Nacatoch sands in Hunt County *Sphenodiscus* and *Baculites* are associated with quantities of *Belemnitella americana*. Other mollusks include *Ostrea*, *Exogyra* and a variety of pelecypods and gastropods, mostly of the large, thick-shelled types. In the same sands near Corsicana and at Chatfield *Sphenodiscus* occurs associated with abundant specimens of the strange irregularly coiled *Nostoceras*. Occasional pachydiscids are found but they are rare. Medium-sized pelecypods and gastropods, especially *Cucullaea* and *Turritella* are abundant.

From this short review of principal types of cephalopod faunas found in the Cretaceous of Texas it is observed that the smooth, involute, obese forms with circular whorl sections (group 1), and the smooth, evolute, obese shells with circular whorl sections (group 2) are not found. The smooth, moderately involute shells with ovate to subquadrate whorl sections such as *Desmoceras* and *Puzosia* (group 3) are found at several levels, but only in the Duck Creek limestone of the lower Washita are these types abundant enough to constitute the dominant element of the fauna. Here they are associated with a few specimens of *Hamites*, *Mortoniceras*, *Prohysteroceras*, and *Inoceramus*. Echinoids and the usual types of pelecypods and gastropods are almost entirely lacking.

Shells with fine to medium sculpture, quadrate to subquadrate whorl sections (group 4a) are the predominant types found in the

Travis Peak formation (lower Trinity) of Central Texas and in the marly clays and shales of Glen Rose age in the Quitman area of West Texas. Echinoids, the large, thick-shelled pelecypods and gastropods and oysters are found, but they are not abundant. Medium-sized gastropods and pelecypods are plentiful.

The heavily sculptured ammonites with quadrate whorl sections (group 4b) are the most common types found in Texas. Their dominance is particularly well demonstrated in the Washita (except lower Duck Creek), Eagle Ford, and Austin chalk. With them are a few of the moderately involute forms with ovate whorl sections (group 3) and the thin-bodied smooth types (group 6), but these have a minor rôle in such faunas. The various uncoiled types (group 7) are often present in considerable numbers. Associated with these ammonoids are the usual run of pelecypods and gastropods, but the large, thick-shelled types and oysters are rarely found, and echinoids are never abundant. The extremely spinose type represented by *Neocardioceras* (group 4c) is found only in the Eagle Ford associated with *Metoicoceras*, *Placenticeras* and uncoiled types.

The tenuous, involute, finely costate, non-tuberculate, or only slightly tuberculate type (group 5) is found abundantly in the Fredericksburg rocks. The only other types of ammonites occurring in any abundance with them are the thin-bodied, smooth engonoceratids. Associated with these ammonites are astounding numbers of echinoids, oysters, and a great variety of thick-shelled gastropods and pelecypods, worm tubes, corals, and crustacean fragments.

The tenuous smooth ammonites (group 6) are found to the approximate exclusion of all others in the Glen Rose of the greater area of Texas and at many places in the Escondido (Navarro). Associated with them are quantities of large, thick-shelled gastropods and pelecypods. Bryozoa, worm tubes, corals, echinoids, and oysters are abundant. The tenuous smooth ammonites are also found in great abundance in the Fredericksburg, but their position is subordinate to that of the tenuous lightly sculptured types. These ammonites are also found sparingly with many of the robustly ornamented quadrate whorled specimens (group 4b) such as the acanthoceratids, mammitids, prionocyclids, and in the Washita pyrite faunas; but they are rarely associated with the desmoceratids of the lower Duck Creek limestones.

The various types of uncoiled ammonoids of the Texas Cretaceous show an overwhelming preference for association with the ammonites characterized by robust sculpture and quadrate whorl sections (group 4) and the other faunas with which these occur. They are

found, however, with the smooth ovate type (group 3). Where the tenuous (groups 5 and 6) ammonites occur to the approximate exclusion of other types as in the Glen Rose, Fredericksburg, and Escondido the uncoiled cephalopods do not occur or are found rarely.

The pyrite faunal zones of the Washita present extremely complex assemblages and probably involve special ecological problems.

It has been noted that ammonites do not occur with rudistids, abundant reef-forming corals, or with *Orbitolina*, and that in a general way the possibility of finding ammonites tends to decrease with the abundance of large, thick-shelled gastropods and pelecypods, and echinoids.

Nautiloids are not numerous or varied in the Texas Cretaceous, but they are found sparingly in all groups of strata with the possible exception of the Eagle Ford. With the single exception of the tenuous *Vorticoceras* of the Glen Rose all species have the general shell form of the modern *Nautilus*.

TYPES OF SEDIMENTS IN WHICH CEPHALOPODS ARE MOST LIKELY TO OCCUR, AND THEIR PALEOECOLOGICAL SIGNIFICANCE

Although the Texas Cretaceous cephalopods occur in a great variety of sediments, they are by no means present in all. It would appear that they definitely avoided waters where certain types of deposits were accumulating and favored others.

In the Texas Cretaceous, ammonites and nautiloids are rare or absent in the purer marine sands and sandstones such as the Trinity and Paluxy where other marine fossils are found. They occur, however, in arenaceous limestones and shales in the Travis Peak, Glen Rose, Eagle Ford, and Nacatoch, but are limited almost entirely to the sculptured forms with quadrate whorls (group 4) and to the tenuous types (groups 5 and 6). The obese, smooth forms (groups 1 and 2) and the smooth forms with ovate whorl sections (group 3) are not found in these arenaceous sediments, and the uncoiled forms such as *Hamites*, *Baculites*, *Scaphites* (group 7) are rarely found. In all probability the purer sands accumulated in waters that were too shallow, or too brackish, or where temperatures changed too rapidly for the well-being of the ammonites. Incidentally, these facts do not argue in favor of the oft-expressed idea that the empty shells of dead ammonites probably floated widely through the waters of the seas.

In the Texas Cretaceous ammonites have not been found in sediments of any kind that bear sun cracks, tracks of land animals (Dinosaurs), littoral fossils, or fine ripple marks, although certain types are occasionally found in the broadly rippled beds of the Fredericks-

burg. The remains of other truly marine invertebrates may be abundant in such sediments as, for example, in much of the Glen Rose.

As already mentioned, ammonites are not found in reef limestones and *Orbitolina* beds. They are seldom found in shell beds or "coquina" limestones, but there are notable exceptions. For example, *Dufrenoya* is found in great abundance in an arenaceous, coquina-like limestone of the Travis Peak, and *Oxytropidoceras* and *Engonoceras* are often incorporated in the *Gryphaea* and *Exogyra* beds of the Goodland. Most types of ammonites appear to have fared poorly under the shallow and rapidly changing conditions where such sediments were accumulating.

Many black shales such as certain black fissile shale beds of the Eagle Ford, Navarro, and other formations seem to have accumulated in an environment unfavorable to ammonites and nautiloids. Indeed, fossils of all kinds are rare in these black shales. This type of environment has been discussed at length by W. H. Twenhofel (1939). He emphasizes the significance of poor circulation and low oxygen content in the bottom waters of such an environment. It would appear, however, that the cephalopods which have been postulated as floaters and nectonic swimmers should be found in the black shales of this environment, but such is not the case.

The most numerous specimens and the greatest varieties of ammonites in the Texas Cretaceous are found in the marls, marly shales and marly limestones such as the Washita marly limestones, the Glen Rose marly shales of West Texas and the calcareous or marly shales of the Eagle Ford. Ammonites are often abundant in the crystalline, chalky, and nodular limestone strata such as those found in the Fredericksburg, Austin chalk, and some Washita strata, but usually the variety under such conditions is not great. The smooth, obese forms with ovate whorl sections (group 3) are limited almost entirely to the marls, and marly limestones.

Ripple marks are frequently observed features in the Texas Cretaceous rocks and since the size and other characteristics of these structures are an indication of the depth at which they were formed they are of some interest here (Bucher, 1917, 1919). Small to medium-sized current and wave ripple marks are abundant in some Glen Rose beds and at many other levels. They were evidently formed at shallow depths. The writer has found no ammonites or nautiloids associated with such structures. In other Glen Rose strata and at several levels in the Fredericksburg large ripples are widely developed. Many of the ripples are 4–6 inches in height and are as much as 5 feet from crest to crest (Scott, 1930). Often the ripples are made of *Gryphaea*,

Exogyra, and other oyster shells. The tenuous ammonites (groups 5 and 6) are occasionally found incorporated in the ripples. These ripples could scarcely have been formed at depths greater than 10–15 fathoms.

FOSSIL CEPHALOPODS HABITATS AND THEIR OBSERVED RELATIONSHIP TO PALEOGEOGRAPHY

From a geographic point of view the ancient seas which ammonites might conceivably have inhabited may be roughly classified into three groups: (1) the open seas of oceanic depth, (2) the geosynclinal seas of the great downwarped depressions often of considerable depth, (3) the usually shallow and extensive epeiric seas covering relatively stable epicontinental areas. The seas of oceanic proportions are of no concern here since little is known of their sediments or of the fossils they might have entombed. The known ammonites lived at various depths and under various other conditions imposed by the seas of the geosynclines and of the epicontinental areas. Furthermore, the conditions of life imposed by latitude characterizing the various seas as boreal, austral, equatorial, *et cetera* are well recognized.

Early students of Mesozoic ammonites in Europe, notably Neumayr, observed the sporadic occurrence of the smooth, obese types of ammonites such as *Phylloceras* and *Lytoceras* and offered the explanation that these genera were equatorial and subequatorial in distribution. This is possibly a partial explanation of why they are not found extensively in the northern regions of Europe, but their occurrence in equatorial and subequatorial Mesozoic deposits is far from general.

Students of the Jurassic and Cretaceous in the Alps and other Mediterranean countries, particularly Kilian and Haug, have shown that *Phylloceras* and *Lytoceras* and other smooth, obese ammonites (groups 1 and 2) do not occur in littoral or neritic deposits, but that *they are the predominant element of the fauna only in the axial regions of the geosynclines and in the deepest or bathyal parts of such basins* (Haug, 1920, p. 838). Here they are often more numerous than all of the other macrofauna combined. The sediments in which they are found are essentially marls. Large, thick-shelled pelecypods and gastropods, corals, bryozoans, oysters, and the tenuous and uncoiled types of cephalopods are wanting or extremely rare. The lightly sculptured ammonites with quadrate whorl sections (group 4a) and the smooth obese forms with ovate whorl sections (group 3) are present but are greatly subordinate in numbers. More often than not the cephalopods of such deposits are preserved as pyrite pseudomorphs.

Surrounding these bathyal areas according to Kilian and Haug, there is always a neritic zone in which other ammonoids often occur

in great profusion to the complete or almost complete exclusion of the smooth, obese forms. With the neritic ammonites are the usual varieties of other faunas including medium-sized gastropods, pelecypods, and limited numbers of echinoids. Finally, around this zone the reef and near-shore littoral deposits do not yield ammonites. The fossils of reef-building animals, and large and thick-shelled gastropods and pelecypods are numerous.

In the Alpine area of southern Europe the bathyal, geosynclinal seas of the Mesozoic were particularly well developed while the neritic and littoral zones surrounding them were extremely narrow. In Texas the opposite is the case. Here the only geosynclinal area of significance during the Cretaceous was in trans-Pecos during Travis Peak and Glen Rose time. Its axis corresponded in a general way to the Quitman Mountains. This area was, in reality, only the shallowed northern extension of one of the great Mexican geosynclines, and does not appear to have been deep enough in Texas to be attractive to *Phylloceras* and *Lytoceras* (groups 1 and 2). These, however, are found in the deeper parts of the basin in Mexico (Böse, 1923; Burckhardt, 1930).

On the other hand, the neritic seas of Texas achieved an areal development which on account of the limitations of space would have been impossible in Europe, and it is possible to subdivide the varied deposits left by them into infraneritic, epineritic, reef, and mud flat zones, all well developed at various levels and lying in order between the bathyal (epibathyal) and littoral zones. Because of the flatness of many of the shore areas the littoral deposits are also widely developed.

In the narrow, neritic areas of Europe the tenuous types of ammonites did not attain any considerable development, and such genera as *Engonoceras*, *Knemiceras*, and *Oxytropidoceras* are rare. In the shallow and abnormally extensive epeiric seas covering Texas, particularly during Glen Rose and Fredericksburg time, these types of ammonites (groups 5 and 6) found a set of living conditions to their liking. They swarmed the seas in enormous numbers and evolved into numerous genera and species.

Lying shoreward from, and surrounding, the epineritic area, are the extensive reef limestones and the mud flat limestones and shales containing sun cracks, animal tracks, dinosaur bones, rain prints, and incredible numbers of *Orbitolina*, large thick-shelled pelecypods, gastropods, echinoids, and other marine fossils. In both these types of sediments and in the bordering littoral deposits ammonites and nautiloids of all kinds are rare or absent.

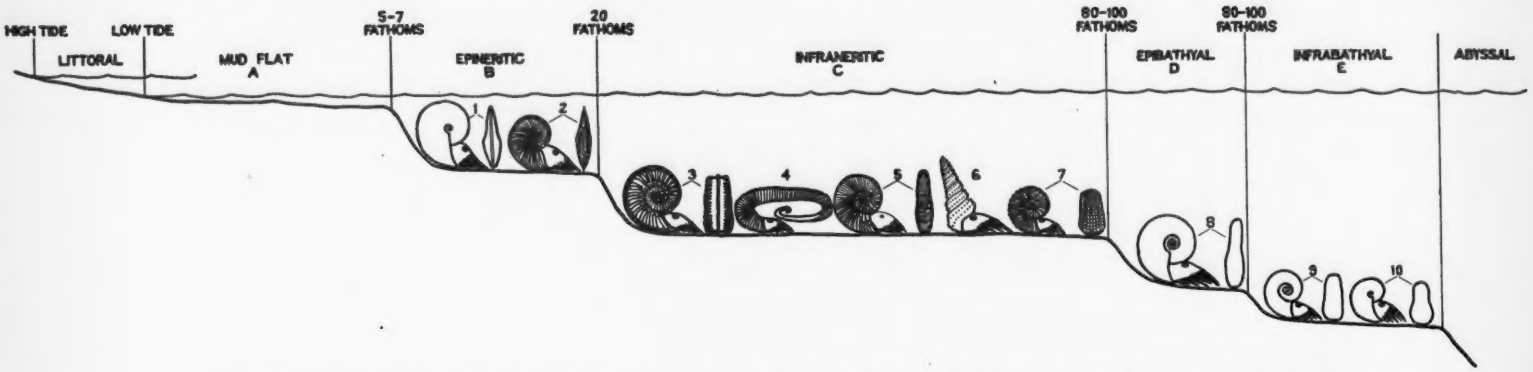

FIG. 8.—Chart suggesting necto-benthonic habitat and bathymetric distribution of principal types of Texas Cretaceous ammonoids as illustrated in Texas area. Drawing is not to scale and terraced arrangement is to better emphasize groupings. There are, of course, numerous gradations from one zone to the other.

1, *Engonoceras*. 2, *Oxytropidoceras*. 3, *Mortoniceras*. 4, *Hamites*. 5, *Hypacanthoplites*. 6, *Turrilites*. 7, *Douvilleiceras*. 8, *Desmoceras*, 9, *Lytoceras*. 10, *Phylloceras* (*Lytoceras* and *Phylloceras*, and related genera are not found in Texas).

The paleogeographic map, supplemented by other data (Fig. 9), shows, in broad outlines, the bathymetric zones of the Mexican and Texas Aptian and Albian seas as indicated by the different types of

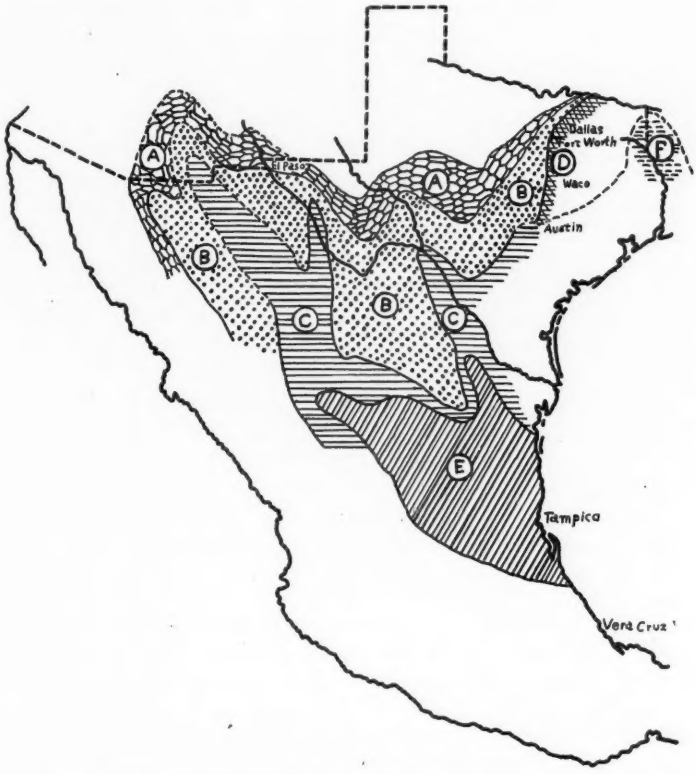

FIG. 9.—Sketch showing distribution of principal bathymetric zones of about Albian (Trinity, Fredericksburg, Washita) time in Texas-Mexican area.

A. Mud flat and associated deposits of Trinity age. *B*. Epineritic (often zoögene) deposits *C*. Infraneritic deposits of Glen Rose and Fredericksburg age. *D*. Epibathyal (lower Washita) and infraneritic (middle and upper Washita) overlapping epineritic deposits of North Texas. *E*. Infrabathyal and epibathyal deposits of geosynclinal regions of central Mexico. *F*. Infraneritic subsurface deposits of Trinity age in Louisiana and East Texas.

cephalopods. Figure 8 illustrates the writer's conception of the bathymetric distribution of the principal types of ammonoids of the Texas Cretaceous area.

INFERRED AND POSSIBLE PALEOECOLOGICAL EFFECTS OF THE WATER MEDIUM, SUCH AS DEPTH, SALINITY, TEMPERATURE, LIGHT, WAVES, CURRENTS, OXYGEN CONTENT, AND BOTTOM UPON AMMONOID LIFE

It has been observed that ammonoids are not normally found in deposits that were put down very near the shore, and that different types are found at varying distances from the old shore. It has, also, been noted that certain types of ammonoids favored the very shallow waters, whereas others sought considerable depths. It is doubtful, however, if either of these factors was, within itself, of great importance to the ammonites. The only factor which varies directly with depth is pressure, and it is possible that variations in pressure which the ammonoids encountered affected their distribution. Temperature and light vary with depth, but they are also dependent on other factors. Waves are phenomena of the surface or near-surface. Regardless of whether the influence of depth was direct or indirect, there can be no question that, other factors being equal, various types of Cretaceous ammonoids were pretty well distributed in bathymetric zones.

It has been pointed out that modern cephalopods are extremely sensitive to reduced salinity and there is good reason to believe that the ancient ammonoids reacted similarly in this respect. Glen Rose seas appear to have been less than 20 fathoms deep over extensive areas as shown by the widespread echinoids, oyster beds, and the fossils of reef-building animals. It is probable that the strata filled with the large thick-shelled gastropods such as *Natica* and *Tylostoma* were deposited at depths of 7 or 8 fathoms. The extensively rippled beds, the coquina limestones and beds filled with borings of clams and worms must have approached the water surface (mud flat). Strata marked by sun cracks and land animal tracks were actually exposed, at times, to the atmosphere. It is conceivable that the Texas area could have been occasionally subjected to violent rain storms amounting to several inches. Far from shore in the shallow seas, even where depths attained 10 or more fathoms, such rains would have reduced the water salinity, to the danger point for the ammonoids. Around the edges of such seas and for considerable distances from the shore great reduction of salinity would have resulted from the influx of fresh water from the lands. Possibly these conditions offer one explanation of why cephalopod fossils are not found in Glen Rose sediments over wide areas in the Texas region. It is also possible that during extended droughts evaporation under a tropical sun could have greatly increased the salinity of the shallow water. This, however, probably did not influence cephalopod life except where evaporation was carried to excess.

It is a well known fact that cephalopod larvae and eggs are extremely intolerant of high temperatures. The heat of a modern Texas summer would easily raise the temperature of a broad body of water, with a depth of 1–10 fathoms, above the tolerance of modern cephalopod young.

In this fact may lie an additional explanation of the absence of ammonoids in the abnormally shallow expanses of the Texas Glen Rose seas. Temperature might also have been a limiting factor in the distribution of the various other types of cephalopods. Pompeckj (1898), Haug (1900), and Kilian (1903) attributed the sporadic occurrence of *Lytoceras* and *Phylloceras* to favorable bathymetric conditions. Haug used the term "stenothermic" for those smooth obese types with circular whorl sections (groups 1, 2) living in the relatively even temperatures of the deep bathyal regions. For the forms dwelling in relatively shallow water and consequently capable of enduring considerable variations of temperature, he used the term "eurythermic."

Whether or not these terms are justifiable to the extent that Haug has used them is difficult to determine. There can be little doubt, however, that some factor associated with depth has influenced the uneven distribution of the different types of ammonoids as outlined in the early pages of this paper.

In defining the neritic zone its lower limit was placed at the lower limit of abundance of photosynthetic plants. This level is directly dependent upon the depth of sunlight penetration, and for most marine waters appears to be about 80–100 fathoms. It may be shallower in areas where the water is turbid and in high latitudes, or a little deeper in tropical and clear waters (Hesse, Allee and Schmidt, 1937). Because of its effect on growing plants, light has a tremendous influence, either directly or indirectly, on all living things. The marine plants do not appear to have served the ammonoids directly as food, and yet only the obese, smooth forms (groups 1, 2, 3) are found in any abundance in deposits formed below the level of abundant plant growth. It appears not improbable that the plants influenced ammonite distribution. The present depth distribution of most shelled gastropods is almost entirely limited to the extent of these "submarine prairies of algae" on which they graze. The lower limit of abundant sculptured ammonites appears to be at about the lower limit of these green plants, that is, at the 80–100 fathom line. Possibly the plants were attractive to the food animals upon which the ammonites were dependent; or perhaps the ammonites used the plants for concealment and protection against their enemies.

It appears that most ammonoids and nautiloids of the Texas

Cretaceous seas avoided all areas where wave and current action assumed any considerable violence. This is indicated by the fact that ammonites are not found in reef deposits; only certain types (groups 5, 6) are found associated with ripple marks and then only with the very large ones. It has been pointed out that *Oxytropidoceras* (tenuous, sculptured, group 5) and *Engonoceras* (tenuous, smooth, group 6) occur in broadly rippled strata of the Walnut and Goodland. These fall under the general heading of large or para-ripples as classified by Bucher (1919). That author emphasized the fact that assembled data on ripple marks is far from adequate for determinations of depth, velocity of currents, magnitude of waves and effects on particles of varying sizes. Bucher believes that the very large para-ripples in which coarse and fine materials are evenly distributed are formed by currents set up in shallow open seas by tides and storms such as tropical hurricanes. He suggests that they could not have developed in depths in excess of 25 meters (12 fathoms). These structures occur in several levels in the Glen Rose and Fredericksburg, and are widespread, having been observed over an area as much as 50 miles wide and 200 miles in length. Other facts agree with conclusions drawn from a study of the ripple marks that these seas were shallow (perhaps less than 12 fathoms), open to the seas and subject to tidal variations and currents; and were, at least periodically, disturbed by violent storms, possibly tropical hurricanes. Most of the time the water must have been clear as indicated by the calcareous sediments but, when violently disturbed so that the relatively large *Gryphaea* shells were whipped into ripples, the finer particles of the bottom must have become suspended, greatly increasing the turbidity of the shallow waters. Apparently, only *Oxytropidoceras* and *Engonoceras* and related forms among the shelled Cephalopoda were able to survive such conditions, in any considerable numbers.

Some kind of Cretaceous ammonoid seems to have been capable of occupying almost any kind of bottom. They, however, probably preferred bottoms of calcareous mud and ooze. Specimens are seldom found in the purer types of sand, but their absence from such deposits should probably be sought in factors other than bottom conditions.

The so-called "black shale environment" was probably unfavorable in extreme cases for ammonoids, but in reality the ammonoids seem to have been able to endure such bottom conditions much better than most mollusks. Many black shales are filled with ammonoids, although the strongly carbonaceous and bituminous shales as a rule are barren of all fossils.

It is possible that bottom effect on the cephalopods was more indirect than direct. The absence of these animals and their food in seas with extremely foul bottoms is easily explained by the absence of oxygen in such stagnant conditions. On the other hand it is apparent that ammonoids did not have oxygen requirements comparable to the reef-forming animals. Incidentally, these facts of distribution of the ammonoids appear to the writer to present the most serious objection to the idea that certain types of ammonoids were planktonic, or that they swam about widely near the surface. If such had been the case, such types as *Macroscaphites*, which has been listed as a floater, should be found indiscriminately in bituminous and carbonaceous deposits and in reef sediments.

The theory that ammonoids floated widely over the oceans after the death of the animal (because of gas accumulation in the chambers) suffers similarly in the light of these facts.

SUMMARY AND CONCLUSIONS

In a problem of this kind the paleoecologist is greatly handicapped by the fact that every criterion available is susceptible of a variety of interpretations. In this paper an effort has been made to consider the pertinent data at hand and then to arrive at an interpretation as near as possible in conformity with all the facts. The following general conclusions appear to be justified.

1. From the data presented the conclusion that most ammonities of the Texas Cretaceous occupied a necto-benthonic habitat seems inescapable. There is some evidence, drawn from a study of shell morphology, that certain types such as the partially uncoiled and hooked *Macroscaphites* and similar forms lived a floating existence. Aside from the fact, however, that shelled animals, other than Foraminifera, do not usually float, all other factors argue against such a mode of life. Some ammonoid species appear to have been good swimmers, but the conclusion that they enjoyed a nectonic existence[8] swimming widely through the seas is not indicated on account of the limited bathymetric and geographic distribution of such types. It is probable that most or all of the Texas Cretaceous ammonoids could swim, but some, such as the tenuous, smooth or lightly sculptured forms (groups 5 and 6) and the straight or strongly recurved types (group 7a) may have been fairly good swimmers. Most, and probably all, species crawled a great deal on the bottom, darted quickly backward from place to place by swimming, or swam in a hovering posi-

[8] H. Douville (1911) arrived at the conclusion that the thin, lightly ornamented types were nectonic swimmers.

tion just above the bottom as they sought their prey, consisting probably of Crustacea, small fishes, *et cetera*. Being capable of at least limited vision, they could stalk their prey or hover in the soft sediments or among the bottom plants and animals at the approach of their enemies.

2. Little is known concerning the eggs and their early developmental stages, even in the living cephalopods, and this is particularly true of *Nautilus*.

3. The young of the ammonoids were probably very similar to the adults except for size. With adulthood, however, they became sexually mature; many species apparently developed restricted apertures to the shell, prolonged rostra as a continuation of the ventral shell wall, or a so-called "hyponomic sinus." Others developed uncoiled, hooked and recurved shells or became spirally and irregularly coiled. Modern biologists would explain these modifications in terms of adaptations. What the purpose of these adaptations may have been is not apparent.

4. The Texas Cretaceous ammonoids are pretty definitely distributed according to bathymetric zones as follows.

(1) The littoral sediments deposited on the shore between tide levels, and sediments deposited in estuaries and other brackish-water areas do not carry ammonites because these cephalopods could not tolerate extremes of temperature, turbulent waters, or reductions in water salinity of any considerable degree.

(2) Seaward from the littoral zone were the shallow Cretaceous seas which approached the low-lying flat lands as extremely shallow bodies of water the sediments of which may be termed mud (sometimes calcareous, sometimes carbonaceous) flats. These solidified muds are characterized by numerous small and medium-sized ripple marks, sun cracks, and the tracks of land and subaquatic animals. It is probable that violent rains greatly reduced the salinity of these seas, but did not make the water brackish, while periods of drought, sunshine, and wind increased the salt concentration. The temperature range of the water was probably considerable. The sediments of this bathymetric zone are termed mud flat deposits. It is believed they were deposited, for the most part, at depths of less than 5–7 fathoms. Ammonites are not found or are so rare as to amount to accidental finds. Large, thick-shelled pelecypods and gastropods, oysters, worm tubes, bryozoans, and *Orbitolina* may be abundant. See zone A on chart (Fig. 8) and on map (Fig. 9).

(3) Closely related to the mud flat seas from the standpoint of ammonoid habitation were the areas of reef-building animals, some-

times referred to as the zoögene facies. Ammonites are not found in the deposits of such seas, probably because the water was too rough and subject to too great variations of temperature and salinity.

(4) Lying adjacent to, and seaward from, the mud flat, zoögene zone are the shallower sediments of the epineritic zone. This bathymetric zone was particularly well represented in Texas by the broad, shallow Cretaceous seas. The sediments of this zone carry myriads of echinoids, large pelecypods and gastropods with thick shells, *Gryphaea*, *Exogyra* and other oyster beds, corals, and crustacean fragments. Evidences of plant growth are abundant. The ammonoids are of the tenuous types such as *Oxytropidoceras*, *Knemiceras*, *Engonoceras*, *Placenticeras* (groups 5, 6). Other types of ammonites are rare or absent.

Some of the sediments are characterized at intervals by the large para-ripples, probably formed by storms (such as tropical hurricanes) and tides. It is believed these sediments of the epineritic zone were deposited at depths ranging from 7 or 8 to 20 fathoms. This bathymetric zone is best represented in the Fredericksburg. It is also developed at certain levels in the Glen Rose, Taylor, Navarro, and equivalent beds. The position of the epineritic sediments of the Texas Cretaceous seas is illustrated by zone B on the chart (Fig. 8) and the map (Fig. 9).

(5) The infraneritic zone lies between depths of about 20 and 80–100 fathoms. The fauna of this bathymetric zone is rich and varied. The ammonites consist of the great hosts of sculptured, and uncoiled and abnormally coiled types (groups 4, 7). The tenuous types of ammonoids are rare or absent. Gastropods, pelecypods, echinoids are numerous and varied. Evidences of plant growth are abundant. The pelecypods and gastropods, however, are not of the large, thick-shelled species. Members of the oyster family are relatively rare. Corals and rudistids are not found. This bathymetric zone or facies is represented in Texas by the Glen Rose (in part) of the Quitman Mountain area, by the Washita of North Texas (except the Duck Creek limestone). The Eagle Ford Austin chalk and certain areas of the Taylor probably fall into this grouping.

The distribution of infraneritic species of the Texas Albian is illustrated by zone C in the chart (Fig. 8) and by zones C and F on the map (Fig. 9).

(6) The epibathyal zone. Smooth ammonoids with ovate to subquadrate whorl sections, such as *Desmoceras*, *Uhligella*, *Puzosia*, lived in a shallower bathyal zone which is designated the epibathyal zone, at or near the 100-fathom line. The absence of algal remains and

the scarcity of gastropods suggests that green plants were not abundant. Ammonoids make up the principal element of the fauna. A few of the sculptured forms (group 4) and certain uncoiled types are found associated with them. The lower Duck Creek limestone represents the only level in Texas where the fauna of this bathymetric zone is well developed, and then only for an extremely brief time. The position of this facies is suggested by the zone D of the chart (Fig. 8), and the map (Fig. 9). The facies also constitutes a large part of zone E of east-central Mexico as shown on the map and possibly other regions.

(7) The infrabathyal zone. The absence in Texas of such obese, smooth genera as *Lytoceras*, *Phylloceras*, *Tetragonites*, *Gaudryceras*, *Kossmattella*, *Jaubertella*, *Silesites* (groups 1, 2) is explained on the basis that the Texas Cretaceous seas were not sufficiently deep to provide the type of living conditions adapted to their well being. Such ammonoids appear to have lived below the 100-fathom line, where light was not sufficiently strong to support green plants. These types also existed far from land in the very centers of great geosynclinal basins. Few other fossils are associated with them. The position of the infrabathyal zone is illustrated by zone E of the chart (Fig. 8) and of the map (Fig. 9, in part).

BIBLIOGRAPHY OF SELECTED REFERENCES

ADKINS, W. S., ARICK, M. B., "Geology of Bell County," *Univ. Texas Bull. 3016* (1930), pp. 1–92.

BENNETT, GEORGE, "Notes on the Pearly Nautilus (*Nautilus pompilius*)," *Ann. Mag. Nat. Hist.*, 4th ser., Vol. 20 (1877), pp. 331–34.

BERRY, E. W., "Cephalopod Adaptations—The Record and Its Interpretation," *Quart. Review of Biology*, Vol. III, No. 1(1928), pp. 92–108.

BOGILD, O. B., "The Shell Structure of the Mollusks," *Mem. de l'Acad. Royale des Sc. et des Lettres de Danemark* (Copenhague, 1930), pp. 322–25 (Cephalopoda).

BÖSE, EMIL, "Algunas faunas Cretacicas di Zacatecas, Durango y Querrero," *Inst. Geol. de Mex.*, Bol. 42 (1923), pp. 1–219, Pls. I–XIX.

BUCHER, W. H., "Large Current Ripples as Indication of Paleogeography," *Proc. Nat. Acad. Sci.*, Vol. III (1917), pp. 285–91.

———, "Ripples and Related Sedimentary Surface Forms and Their Paleogeographic Interpretations," *Amer. Jour. Sci.*, 4th Ser., Vol. 47 (1919), pp. 149–210, 241–69.

BURCKHARDT, CARLOS, "Etude synthetique sur le Mesozoique Mexicain," *Mem. Soc. Pal. Suisse*, Vols. IV, V (1930), pp. 1–280.

CLEMENTS, FREDERIC E., "Scope and Significance of Paleoecology," *Bull. Geol. Soc. America*, Vol. 29 (1918), pp. 369–74.

COOKE, A. H., *The Cambridge Natural History*, "Molluscs" (1913). 444 pp.

CRICK, G. C., "Muscular Attachment of the Animal to Its Shell in Ammonoidea," *Trans. Linn. Soc.*, Ser. 2, Vol. 7 (1898), pp. 71–113.

CUMINGS, E. R., "Reefs or Bioherms?" *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 331–32.

DIENER, C., "A Critical Phase in the History of Ammonites," *Amer. Jour. Sci.*, Vol. IV (August, 1922), pp. 120–26.

DOLLO, L., "Les cephalopodes adapti a la vie nectique secondaire et a la vie benthique tertiare," *Zoologisch. Jahrb. Suppl.* (1912), pp. 105–40.

DOUVILLE, H., "Sur la classification des ceratites de la craie," *Bull. Soc. Geol. Fr.*, Ser. 3, Vol. 18 (1890), pp. 275–92.

———, "Influence de la mode de vie sur la ligne suturale des ammonites appartenant a la famille des cosmoceratides," *Compt. Rend. Acad. Sci.*, tome 156 (1913), pp. 170–74.

DUNBAR, C. O., "Phases of Cephalopod Adaptation," Ch. VI of *Organic Adaptation to Environment* (1924).

FOERSTE, AUG. F., "Silurian Cephalopods of the Port Daniel Area on Gaspé Peninsula in Eastern Canada," *Denison Univ. Bull.*, Vol. 36 (1936), pp. 21–92, Pls. 4–26.

GRIFFIN, L. E., "The Anatomy of *Nautilus Pompilius*," *Mem. Nat. Acad. Sci.*, Vol. 8 (1900).

HAUG, EMILE, "Les geosynclinaux et les aires continentales," *Bull. Soc. Geol. de Fr.*, 3e Ser., Vol. 28 (1900), pp. 617–711.

———, *Traité de Geologie* (1920).

HESSE, RICHARD, ALLEE, W. C., and SCHMIDT, KARL P., *Ecological Animal Geography*, John Wiley and Sons (1937), 538 pp.

HEWATT, W. G., "The Littoral Zone," *Micropaleontology Bulletin*, Vol. 4 (1933), pp. 80–82.

HYATT, A., "Genera of Fossil Cephalopods," *Boston Soc. Nat. Hist. Proc.*, Vol. 22 (1884), pp. 253–338.

———, "The Phylogeny of Acquired Characteristics," *Proc. Amer. Phil. Soc.*, Vol. 32, No. 143 (1894), pp. 349–616, Pls. I–XIX.

KILIAN, W., "Note sur le genre de vie des ammonites," *Bull. Soc. Geol. de France*, ser. 4, tome 3 (1903), p. 196.

LANKESTER, E. RAY, *Treatise on Zoology*, Part V, "Mollusca." London (1906).

MACGINITIE, G. E., "Life in a Marine Mud Flat," *Turtox News*, Vol. 18, No. 1 (1940), pp. 4–6.

MILLER, A. K., and FURNISH, W. M., "Paleoecology of the Paleozoic Cephalopods," *Report of Committe on Paleoecology, Nat. Research Council* (1937), pp. 54–63.

MOREMAN, W. L., "Fossil Zones of the Eagle Ford of North Texas," *Jour. Pal.*, Vol. I (1927), pp. 89–101, Pls. 13–15.

POMPECKJ, M., "Paleontologische und stratigraphische Natizen an Anatolien," *Zeitschs. d. Deutschen Geol. Ges.*, Vol. XLIX (1898).

ROGERS, JULIA ELLEN, *The Shell Book*, Doubleday, Page and Company (1908), 463 pp.

SCOTT, GAYLE, "Some Gerontic Ammonites of the Duck Creek Formation," *Texas Christian Univ. Quar.*, Vol. 1, No. 1 (1924), pp. 5–22, Pls. 1–9.

———, "Ripples of Large Size in the Fredericksburg Rocks West of Fort Worth, Texas," *Univ. Texas Bull. 3001* (1930), pp. 53–56.

TRUEMAN, A. E., "Aspects of Ontogeny in the Study of Ammonite Evolution," *Jour. Geol.*, Vol. 30 (1922), pp. 140–43.

TWENHOFEL, W. H., "Organisms and Their Environment," *Report of Committee on Paleoecology, Nat. Research Council* (1936), pp. 1–9.

———, "Environments of Origin of Black Shales," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), pp. 1178–98.

VAUGHAN, T. WAYLAND, "Present Trends in the Investigation of the Relations of Marine Organisms to Their Environment," *Ecological Monographs*, Vol. 4 (1934), pp. 501–22.

———, "Ecology of Modern Marine Organisms with Reference to Paleogeography," *Bull. Geol. Soc. America*, Vol. 51, No. 3 (1940), pp. 433–68.

WILLEY, ARTHUR, *Zoölogical Results Based on Material from New Britain, New Guinea, Loyalty Islands and Elsewhere, Collected during the Years 1895, 1896, and 1897*, Cambridge Univ. Press (1902).

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PARTNERSHIP BETWEEN GEOLOGY AND GEOPHYSICS IN PROSPECTING FOR OIL[1]

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It is my privilege to extend to the American Association of Petroleum Geologists, on this celebration of its silver anniversary, the felicitations of the Society of Exploration Geophysicists. The contemplation of twenty-five years of sound and progressive history is no doubt a source of deep satisfaction to those who founded the Association and to many others who helped to make it grow. Simultaneously, the Society which I am here representing is celebrating its tin anniversary. When this coincidence first came to my attention, I hoped to find that the alloying of silver and tin, a noble and a base metal, produces a product with useful properties not possessed by either component alone. The rhetorical advantages which would have followed are obvious. The metallurgical literature, however, dashed this hope so that this allegorical approach to my subject had to be abandoned.

That there exist broad areas of common interest between geologists and geophysicists is almost too obvious to require mention. That this is realized is evidenced by the substantial overlap in the membership of our respective professional organizations. In fact, three out of every eight members of the Society of Exploration Geophysicists are members of the American Association of Petroleum Geologists. Dr. Donald Barton, who probably contributed more than any other one man to the founding of our Society, was its first president and later also president of the Association.

The existence of areas of common interest and their recognition are two important factors which invite partnership. It is quite generally realized that the two professional groups which we represent deal with substantially the same objectives, and that it is only in the manner in which they are approached that we differ. Each has a contribution to make to the achievement of the common goal. This is the essential prerequisite to a partnership. It is in that light that I like to view the coöperative effort of our two professional groups in the business of prospecting.

[1] Address of the president of the Society of Exploration Geophysicists before the joint meeting of the American Association of Petroleum Geologists, the Society of Paleontologists and Mineralogists and the Society of Exploration Geophysicists at Chicago, April 10, 1940. Reprinted, by permission, from *Geophysics*, Vol. 5, No. 3 (July, 1940).

[2] Gulf Research and Development Company.

Partnerships vary widely in character. They most completely fulfill their purpose when each partner appreciates fully the special talents of the other and when a mutual understanding exists as to how they can best be coördinated so as to produce the most favorable results. That this mutual understanding is insufficiently developed between geologists and geophysicists is well known. That its cultivation is worthy of the best efforts of all concerned is a point I wish to make. The more effective coördination of the geological and geophysical aspects of prospecting seem to me the outstanding need of the day in this branch of the oil industry. Its accomplishment will in my judgment pay greater dividends than any advance which can be anticipated in the techniques of either geology or geophysics.

The result of geophysical prospecting depends quite as much on the quality of the reaction to the geophysical picture as on the merit of the data on which the reaction is based. With full realization of the shortcomings of many geophysical pictures, I venture to suggest that in the past the data have in general been better than the utilization of them. In the nature of things, this must be a matter of opinion, but it is an opinion that is widely held among competent geophysicists.

The process of defining practically any subsurface structure on the basis of geophysical or any other evidence is almost invariably similar to a detective job in which the available evidence is fragmentary. The fragments have to be fitted together in the most reasonable manner. The resulting contour map can not possibly portray adequately what is strong and what is weak. Yet this map is too often the sole basis of all subsequent action. Geologists have been known to become annoyed when the geophysicist qualifies his picture with ifs and buts. Yet a knowledge of the weaknesses in the evidence is necessary to correctly appraise the risks which are being faced. Although it has been said facetiously that if management fully understood the risks, few would be undertaken; I nevertheless believe that the correct appraisal of the risks being assumed is essential to a sound prospecting program. When the evidence available is wholly geophysical the chief geologist and perhaps even management can not afford to consider less than all the geophysicist knows about the prospect.

In the early days of geophysical operations it was a quite common practice to withhold from geophysicists information already available concerning the areas in which they were working. The purpose, no doubt, was to prevent the geophysical findings from being biased by the pre-existing knowledge. The circumstances surrounding much of the early work probably made this precaution necessary, but the effect unquestionably was to retard the development of the geophysi-

cal art. Fortunately this attitude has been disappearing rapidly and to-day only erosional remnants remain, usually capped by exceptionally resistant rock.

It may be useful to enumerate some of the factors on which the success of geophysical prospecting depends. This is done in the accompanying table.

TABLE I

FACTORS ON WHICH THE SUCCESS OF GEOPHYSICAL PROSPECTING DEPENDS

1. Choice of a geophysical program
   a. To be in harmony with the general prospecting policy of the company
   b. To defend most effectively against competitive activity
2. Choice of a geophysical method
   a. In view of the general geology of the area to be prospected
   b. In view of the nature and extent of prospecting already done in the area
   c. In view of the physiographic and geographic character of the area to be prospected
   d. In view of competitive activity
   e. In view of the relative availability of different methods
   f. In view of relative costs
3. The control of geophysical operations by
   a. Considerations of economy
   b. Legal considerations
   c. Technical considerations
4. The quality of the geophysical results
5. The quality of the follow-up of geophysical findings

This list is undoubtedly incomplete and the classification it presents capable of improvement, but it will serve our purposes as it stands. It indicates that the factors which contribute to success or failure are numerous and often strongly interdependent. That is why management finds it so difficult to analyze such failures as occur and to locate the weak spots and remedy the trouble. It explains why the medicine may be handed out to the wrong department and justifies the suspicion that at times the prescriber should take the medicine himself. Everybody who deals administratively with exploration should have such a list but I doubt if very many people have one.

A geophysical program may be a model of excellence in all other respects and fail simply because it does not fit in with the general prospecting policy of the company. This lack of adaptation may apply only to parts or certain aspects of the operation as well as to the whole. The maladjustment of program to needs is a fundamental weakness, the avoidance of which is a primary prerequisite to success.

An adequate defense against competitive activity has varied aspects and consequently in considering this angle of the geophysical program there must be taken into account general policy, the nature of the geologic province and available techniques as well as the nature and volume of the competing effort.

In deciding which geophysical method or combination of methods

to use under a given set of circumstances, close attention must be given to the inherent suitability of each method for investigating the problem under consideration. It may not be feasible to use the most suitable one and, as a matter of expediency, a second or third choice procedure may have to be adopted. There is a real danger that concessions to expediency become habitual and that they are made when the need for making them does not exist. Constant effort is required to assure the use of the best possible method which conflicting practical considerations will permit and to prevent the complete devitalization of the geophysical attack by obstacles which loom greater in the minds of men than they do in actual fact.

Time does not permit our discussing in detail the various factors which have been mentioned as having a bearing on the success of geophysical operations. It is to be noted that they can fail at many points and that in the initiation, execution and exploitation of geophysical programs, executives, geologists, and geophysicists have intricately interlaced opportunities and responsibilities. The well coördinated coöperation of all is necessary to success.

By way of illustration, brief mention may be made of a successful geophysical campaign of which I have intimate personal knowledge. Very late in 1936 or very early in 1937 a well drilling in Lamar County, Mississippi, was reported to have encountered anhydrite at relatively shallow depth. To geologists familiar with the stratigraphy of the area, this immediately suggested cap rock. It seemed probable that on drilling deeper the well would encounter salt and that the discovery of the first salt dome to be found in Mississippi would thus be confirmed. As you all know, this anticipation was realized a short time later. My company rushed a gravimeter party to the environment of the well and the survey made promptly revealed the existence of a gravity minimum typical of a piercement-type salt dome. A second gravimeter party was moved into the area and a complete systematic gravity survey of a substantial part of southern Mississippi was initiated. The existence of a salt-dome basin of considerable extent was revealed. Over a period of many months salt-dome prospects were discovered at an average rate of one per week. Since the gravity survey systematically covered the entire area, nothing could be learned from the operation as to what if anything was being found and it was not until the leasing was being done that any information became available.

The geophysical cost of this operation per prospect was nominal. The land costs were also quite moderate. This campaign allowed the assembly of lease blocks on favorable prospects in an area of which

the oil possibilities remained to be ascertained. The cost per block undoubtedly represented a new low in discovery cost for the average of a number of prospects.

I will leave it to the reader to analyze this example for the elements of its success. It was an example of partnership at its best. The availability and smooth performance of gravimeters was of course an essential prerequisite. Work on the development of these instruments had been begun four years earlier. Had this not been true the campaign in Mississippi would have had an entirely different history, a much less favorable one.

This brings to mind the question as to how actual prospecting by geophysical methods should be related to pertinent research and development. The needs and problems in any field of endeavor are the more easily perceived the closer one is to the job. It is best to have instruments for field use designed only by men who have experienced the circumstances of actual field operation. In the nature of things some separation of the research and development from the operating function is unavoidable. But the unfavorable effect of this separation can be minimized by a judicious and continual transfer of men between the two groups. No amount of description will fully substitute for actually seeing a thing. No system of reporting, however complete, will adequately inform a research and development group regarding the problems of the operating group. It is as true in geophysics as in other fields that necessity is the mother of invention. The necessities in geophysics are faced primarily in the field operations. In line with these considerations a geophysical staff is conveniently divided into three classifications:

a. Primarily research and development men,
b. Men fitted for both development and field operations,
c. Primarily field operators.

The men in the middle group are those who should be shifted back and forth between the other groups.

The normal conduct of geophysical operations involves a complex series of compromises between considerations of geology, geography, geophysics, finance, law, and related management policies. In order that the subject may be viewed objectively and in perspective, it is necessary that the representative of each specialty have some working knowledge of the other matters which are involved, and that some machinery exists for developing a composite picture to which each factor contributes no more and no less than its appropriate part. This is a fallow field for the partnership of geology and geophysics.

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GEOLOGY IN THE PETROLEUM INDUSTRY[1]

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The contribution of geology to the success of the oil-producing industry has been appraised repeatedly and by diverse authorities. The common procedure has been to measure the accomplishment in terms of the number of oil fields or barrels of oil reserves discovered by geologists. Yet it has long been obvious that such computations fail to tell the whole story. Geology has gradually come to occupy a field in the petroleum industry much broader than mere exploration for new reserves.

The evaluation is not easily made. A contemporary philosopher has written:

> . . . objective judgments about society are difficult to arrive at. This is because the scientist is a part of the material he examines and occupies a particular position within it; a position usually entailing passionate opinion. He can, however, roughly distinguish such opinion from ascertained facts.

For the geologist in the petroleum industry to distinguish opinion from fact requires a nice discrimination and to pass objective judgment he must be possessed of true humility.

In the London office of an international oil company a number of years ago there hung a portrait of a commanding, bearded figure, the company's chief geologist and the alleged discoverer of one of the world's great oil fields. To-day the portrait is gone; it was finally removed when the realization became general that dozens of men—geologists, engineers, drillers—all had contributed materially to the discovery in question. With the decline of the age of hero worship eminent petroleum geologists have lost something of the halos that formerly distinguished them. Seldom are oil fields found through the unaided effort of a single individual, however fondly we may cling to the legends of geologic prowess in the professional generation now about to pass.

In the early years of this century when geology first began to make itself effective in oil finding, the established producing companies, overcoming a natural skepticism, promptly resolved to avail themselves of this new and promising aid. To this end they canvassed the staff of the United States Geological Survey and faculties of leading universities, seeking to persuade geologists in these organizations to

[1] This article originally appeared in the A.A.P.G. number of the *Oil Weekly* of April 8, under the title of "Oil-Field Development Is a Geological Enterprise." It is reprinted by permission.

[2] Standard Oil Company (New Jersey), 30 Rockefeller Plaza.

abandon the security and prestige of civil and academic posts for the freedom and greater material rewards of service "in trade." In this manner there was recruited a small army of shock troops in petroleum geology. Following these pioneers there sprang up within a few years in the larger oil-producing centers a class of free-lance experts; consulting geologists whose services were available on a fee basis. Through these consultants the small independent wildcatter also was provided with geologic guidance.

Meantime the larger companies were proceeding to build up geologic departments under their chief geologists, employing for this purpose graduates in geology from universities and colleges all over the country. And to meet this demand the schools in turn rapidly built up courses of instruction in petroleum geology. Young men everywhere rushed into petroleum geology, lured by the fascination of tracking down and reducing to possession this elusive quarry, the obscurely and deeply buried oil field. Thus, within a surprisingly short period the available supply of geologists exceeded the demand of oil producers for purely geologic staffs. Soon these graduates in petroleum geology, unable to secure employment in geological departments of oil companies, began to seek work in other departments. They got jobs as roughnecks; as roustabouts; they rose from these lowest ranks to the position of drillers and foremen; they served as scouts and lease men. With this development geology, which had previously been merely a narrow path to a specialist's job in oil finding, widened into a broad avenue of approach to the whole enterprise of producing oil. In due time geologists, having acquired the necessary experience, financed and drilled wildcat wells for themselves; formed their own producing companies. Simultaneously other geologists, having started in various capacities with the larger producing units, advanced in rank until many of them came to hold responsbile executive positions.

In this fashion geologic principles gradually came to permeate the whole industry. For the first time, perhaps, the scientific method began to make itself felt in American industry. Analysis and the persistent search for facts slowly replaced hunch, inherited opinion, tradition and dogma; objectivity established itself over an expanding area of operation. Coincidently with this change, geology manifested a correspondingly increased effectiveness in its own peculiar domain. As long as geology had been dispensed by a detached chief geologist, a consulting geologist, or even a geologic department, carefully insulated from any contact with other producing functions, only a mediocre success in oil finding was attained. But as men with a

geologic point of view began to assume responsibilities and to influence decisions throughout the whole oil-producing enterprise, success in finding mounted as though by magic. Dry-hole averages decreased, proved reserves mounted, recoveries per well and per acre improved and unit costs declined all through the operation.

So it is that petroleum geology has steadily seeped out through the barriers that once confined it to the field of exploration and discovery, until it literally saturates the entire structure of the oil-producing industry. So all-pervasive has this dissemination been that no longer does any operation of the oil producer escape a geologic coloration. This conquest of the industry by geology has been not unlike the process of metasomatism, to borrow an appropriate if somewhat imposing term from the hard-rock geologists. Metasomatism is that important process in ore deposition whereby the invading solution, although it leaves the outward form or body of the host rock unchanged, nevertheless, entirely transforms its intrinsic character, replacing the original internal constituents, molecule by molecule, with substitutes of its own selection. So has geology reformed the business of producing oil. The industry has refashioned its whole technique, assembling it anew in an undeniably geologic setting. To-day no engineer determines an optimum rate of production, no drilling crew sets an oil string, no conservation officer promulgates a spacing order for a new field, but he draws importantly, albeit unconsciously, perhaps, on the collective geologic experience of the industry in the performance of his task.

All this is as it should be and there is in the development no occasion for surprise to any competent student of the oil industry. In its true character the exploitation of natural reservoirs of petroleum in the earth's crust constitutes a purely geologic enterprise. When it is comprehended and undertaken as such rather than as a game of chance or an adventure in clairvoyance, coupled only with the mechanical problem of sinking wells and lifting fluids, as the pioneer producers conceived it to be, it is only natural that greater success should attend the effort.

There is exemplified in the modern technique of the oil-producing industry as herein described a way of doing things that is peculiarly American. Only in a society where the gentleman, the educated professional specialist, labors freely with his hands, unembarrassed, at menial tasks, can a coöperative effort of this character attain full success. It is no mere coincidence that most of the oil fields of the world have been found by Americans. Search for oil fields succeeds best through the method of intimate and all inclusive coöperation in which American workers excel. The contrary method is illustrated by recent

experience in oil finding in some of the totalitarian countries. In Russia (that land of the classless society) geologists comprise one category, drilling experts another, production engineers another. Each group is insulated rigidly from the others; each reports to and is directed by a different authority. The geologist in his work is denied the great advantage of that identity of viewpcint with the driller and the producer on their problems, which first-hand personal experience would give him. The driller and producer alike, in turn, suffer from a similar lack of any geologic understanding. In this hierarchy ultimate control is despotic, centralized and remote from the scene of the actual struggle. Some of the most brilliant individual petroleum geologists in the world are Russians. Within the confines of Russia lies much of the most promising petroleum province in the world. Over the last twenty years Russia has devoted intense effort to finding and producing more oil. Yet to-day Russia starves for oil while America sells oil to the world. America produces currently about six barrels of oil for every barrel Russia can produce. America's past production far exceeds that of Russia and her proved reserves bulk more than twice those of Russia.

Even a brief review of the record of finding and producing the world's oil, viewing the matter in the light of American experience, arouses some unconventional suspicions. In England, that tight little isle, oil has at length been discovered by Americans. After two generations of sterile skepticism there is now little reason to doubt that England, despite its long history of failure, is potentially just as prolific a source of oil as geologically similar areas in the United States which have long been exploited with moderate success. Americans recently discovered the first really commercial oil field ever known in Hungary. Americans also have discovered and developed within the last few years the most important oil field ever found in Germany, although Germany has scores of salt domes and other favorable attributes of oil-producing regions and has carried on studious, diligent, and intelligent search for oil fields for years, spurred to unusual effort in this realm of her internal economy by her dire need for liquid fuels and lubricants. How is it to be explained that these long-established, progressive societies, in spite of desperate need, fail to find the resources which are revealed so quickly and easily within their own borders by the American technique? The suspicion grows that physical conditions within the earth's crust impose fewer and less formidable obstacles to the development of commercial oil fields over much of the land area of the globe than are raised up by our prevailing mental and social climates of opinion. The limitations put upon the discovery of

oil on earth to-day are more mental and social than physical. Gold is where you find it, as the old adage has it, but oil must be sought first, at least, in the mind. If there be any validity whatever to this view, the implications can not but be significant to other industries, to science at large, to depressed national economies and to nations torn by war.

But to return to the subject under discussion. In summary, it may be said that the early participation of geologists in the work of solving the problems of the oil-producing industry, initiated as it was within a few years after the birth of the American industry, constitutes a pioneer venture of science into industry. By the time fellowships for scientists to work on industrial problems in general came to be established in America, the petroleum geologist had already attained flattering recognition. Geology, the inexact, cultural science, operating in the field of oil production, blazed a trail along which its older sister sciences, chemistry and physics, advanced years later to revolutionize the technique and efficiency of petroleum refining. But the greatest contribution of geology to the petroleum industry arises from its success in impressing upon the industry a comprehension of its own true character, namely, that of a geological enterprise. In doing this it has also demonstrated a most effective method for coöperative effort between industry and science generally; that is, the effective dissemination of the basic facts of the science in question and of the scientific point of view throughout the rank and file of the personnel of the whole industry.

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OIL-FIELD WATERS OF WYOMING AND THEIR RELATION TO GEOLOGICAL FORMATIONS[1]

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ABSTRACT

Tabular and graphic analyses of waters from the oil- and gas-producing zones of Wyoming are presented and discussed.

Post-Chugwater waters are essentially solutions or sodium salts, whereas in pre-Chugwater waters calcium and magnesium sulphates ordinarily predominate.

Frontier waters are solutions of sodium chloride and sodium bicarbonate in varying proportions. Waters from the "Dakota group" are solutions of sodium salts, but contain appreciable quantities of sulphate. Most Sundance waters are solutions of sodium salts similar, except for concentration, to Frontier and "Dakota group" waters. Chugwater water is exceptionally concentrated, ranging from 30,000 to 50,000 parts per million. Embar waters contain hydrogen sulphide and are the youngest subsurface waters in which secondary salinity is prominent. In most of the Tensleep waters secondary characteristics dominate the chemical system with secondary salinity ordinarily occupying 40–70 per cent. Madison waters commonly have a somewhat higher secondary salinity than Tensleep waters in the same area, but otherwise resemble them.

The analyses indicate that all the oil-field waters of Wyoming have been considerably modified by the infiltration of surface water.

INTRODUCTION

The first extensive application of water analyses to the production of oil and gas in the Rocky Mountain region was made in the Salt Creek, Wyoming, oil field in 1922–25, by the Midwest Refining Company. The present chemical laboratory of the Geological Survey at Midwest, Wyoming, was established in 1924 and since that date has analyzed, classified, and correlated more than 3,000 water samples from oil and gas zones in the Rocky Mountain region, including a complete water survey of the Salt Creek field. In the majority of waters analyzed geological correlations have been possible, and it is not unusual to identify lithologic units in wildcat wells many miles from producing fields by the similarity of waters.

The correlation of subsurface waters with formations and members thereof is possible because water from a particular zone is rather constant in composition in a given area throughout the years; in fact, in the Rocky Mountain region, samples of water taken 5–8 years after a sand was first penetrated show the same characteristics, constituents, and concentration as were originally present.

This paper presents tabular and graphic analyses of typical waters encountered in the oil and gas fields of Wyoming, except those areas

[1] Published by permission of the director of the Geological Survey. Manuscript received, June 22, 1939; revised manuscript, May 1, 1940.

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where lenticularity of beds, severe faulting, and other factors have prevented free migration of water, such as in the LaBarge field. The analyses have been carefully correlated with the logs of wells in the respective fields by petroleum engineers of the Geological Survey.

ACKNOWLEDGMENTS

The writer is indebted to the following members of the Geological Survey: to H. J. Duncan, who had general supervision of the work; to Herman Stabler, L. G. Snow, R. D. Ferguson, C. A. Hauptman, R. M. Larsen, J. R. Schwabrow, E. A. Swedenborg, and T. F. Stipp, for both general and specific criticism; to R. R. Patterson and J. H. Thompson for preparing the illustrations; and to C. E. Dobbin who generously contributed his extensive knowledge and data on the geology of the state.

METHOD OF ANALYSIS

The primary purpose of the investigations described is to identify the stratigraphic positions of analyzed water samples. As there are easily distinguishable differences between most waters—differences so great that a variation of several parts per million in the determination of the ions will not invalidate the results—a rather high percentage of error is permissible in this type of analysis; in fact, a highly accurate analysis is unnecessary, because of contamination by drilling mud, variation in composition over a structure, and other factors. As a result, all available short cuts are used, only the common ions are determined analytically, and sodium is calculated. Minor constituents are not determined quantitatively, and hydrogen sulphide, iron, and rarer elements are reported only as present. Sulphate, calcium, and magnesium, when occurring in quantities of less than five parts per million, are usually reported as "trace." Analytical procedure is standard and is carried out with great precision.

CLASSIFICATION OF WATERS

The Palmer[3] system of water classification has been followed, as it emphasizes important differences between waters in geochemical relationship. Palmer groups those radicles that are either chemically similar or geologically associated; that is, the common bases, sodium and potassium, are grouped as alkalies; calcium and magnesium are grouped as the alkaline earths; sulphate, chloride, and nitrate are grouped as the strong acids; and carbonate, bicarbonate, and sulphide are grouped as weak acids. Using these four groups, Palmer separated

[3] Chase Palmer, "The Geochemical Interpretation of Water Analyses," *U. S. Geol. Survey Bull. 479* (1911).

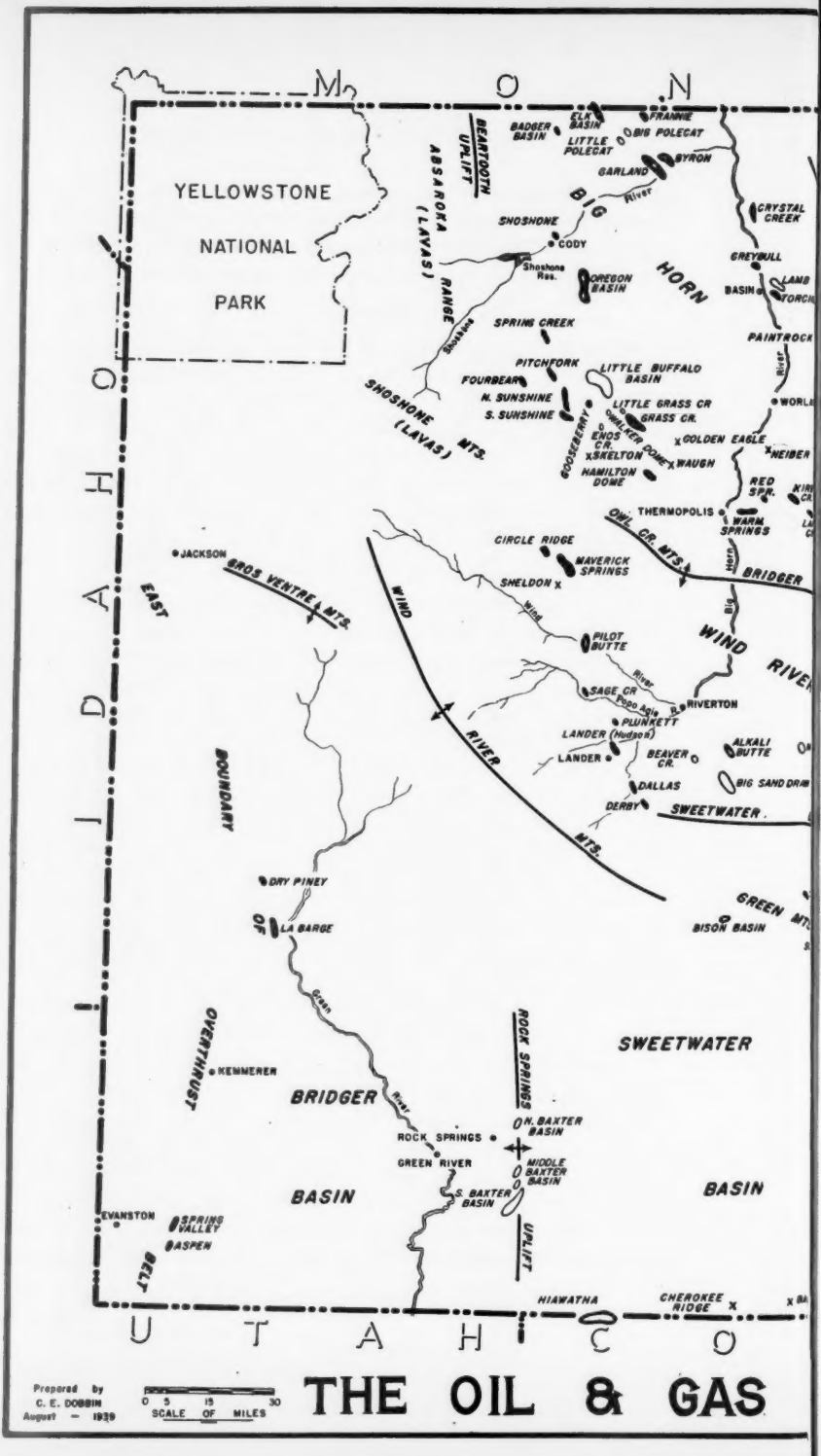


FIG. 1 (west half)

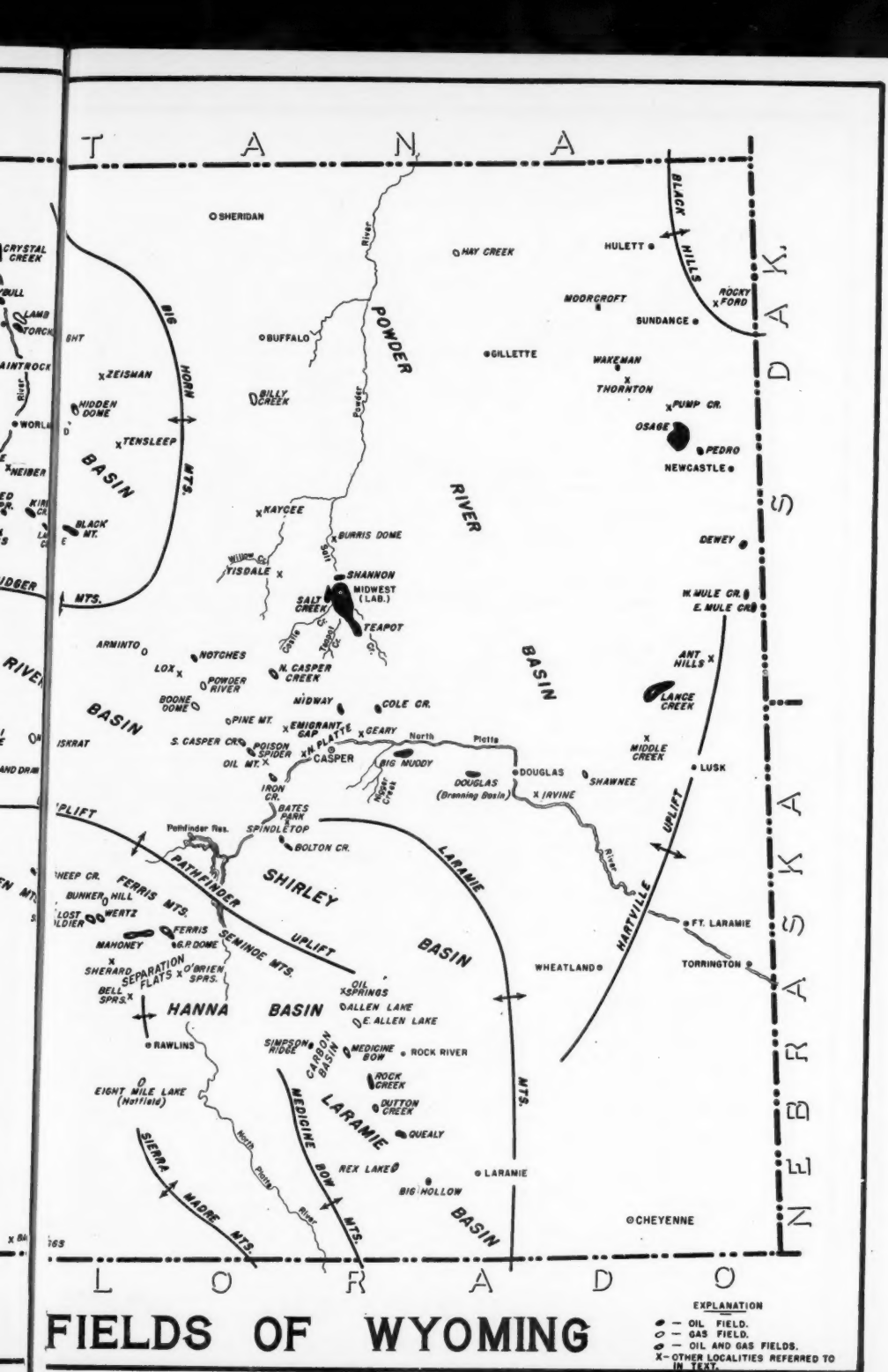


FIG. 1 (east half)

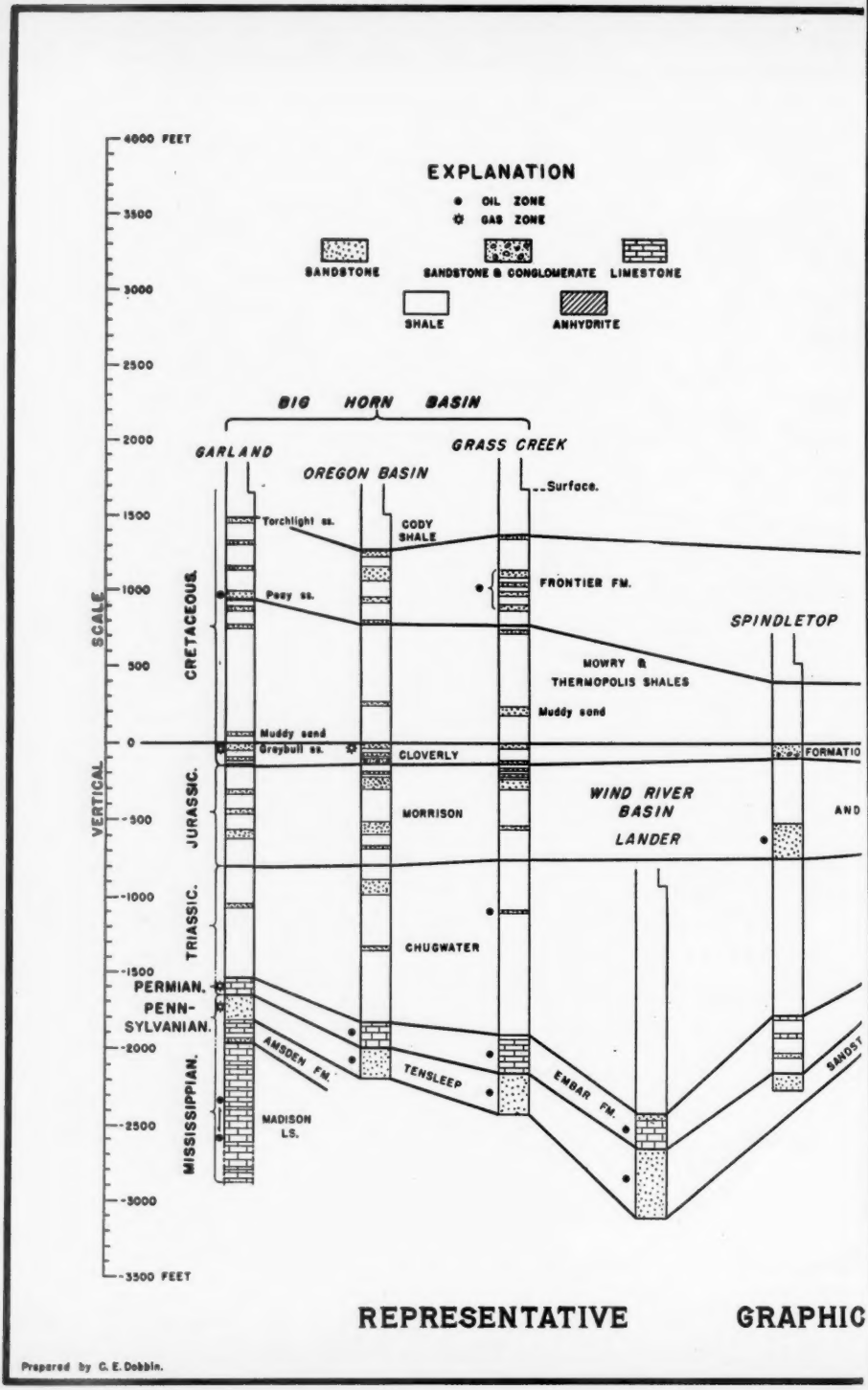
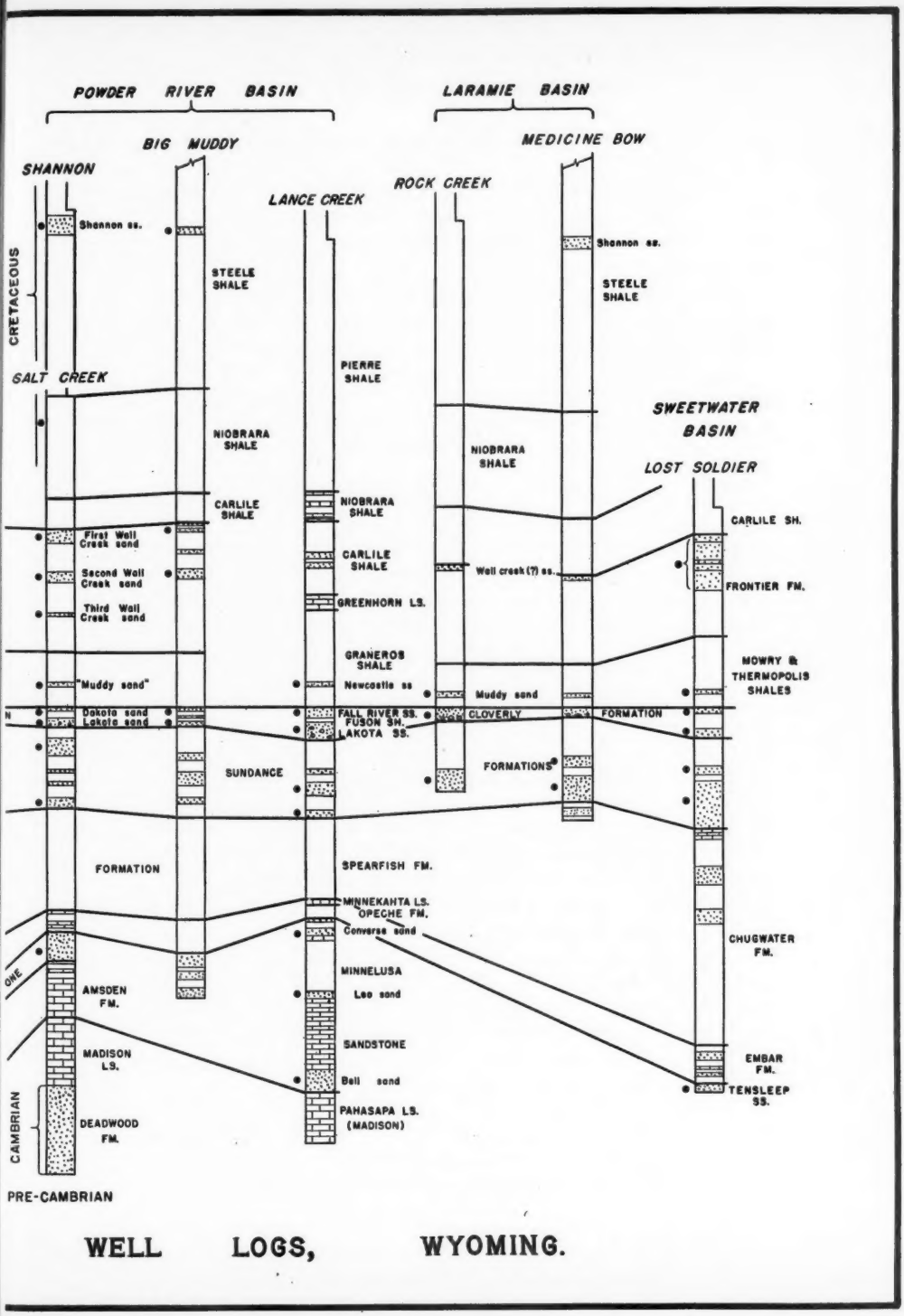


FIG. 2 (north part)



WELL LOGS, WYOMING.

FIG. 2 (south part)

natural waters into four classes, according to the reacting value of these radicles.

The alkalies in connection with the strong acids cause primary salinity. If the strong acids are greater than the alkalies, excess of strong acids with an equal value of alkaline earths induces secondary salinity.

Primary alkalinity is excess of the alkalies over the strong acids, with an equal value of the weak acids. Secondary alkalinity is excess of the weak acids combined with an equal value of alkaline earths.

As secondary salinity and primary alkalinity are incompatible, each natural water will have two or three of these properties of reaction—never all four. In addition, the percentages of sulphate salinity and chloride salinity are computed, and may be used as criteria for comparison.

Primary salinity is common to all waters. A water featured by primary alkalinity contains silica and is a good solvent of granitic rocks, such as the surface water of mountain ranges. A water characterized by secondary salinity is permanently hard and is ordinarily derived from marine deposits. A secondary alkaline water is temporarily hard, and ordinarily comes from calcareous beds.

GENERAL CHARACTER OF PRODUCING SANDS

With some exceptions, such as most of the Cloverly formation, parts of the Dakota (?) sandstone, and the Mesaverde formation, of Cretaceous age, and the Wasatch formation of Eocene age, the commercial oil and gas zones of Wyoming are largely of marine origin, ranging in age from Mississippian to Eocene (Fig. 2). The sandstones of the Sundance formation (Jurassic) and the Tensleep sandstone (Pennsylvanian) are fairly continuous and rather uniform in character over the state, and have had their connate sea water largely replaced by circulating meteoric waters, as have the irregular and lenticular Dakota (?) and Cloverly sandstones.

The sandstone members of the Frontier formation, such as the several Wall Creeks, the Torchlight, and the Peay, and the Shannon sandstone member of the Steele shale, all of Upper Cretaceous age, are rather lenticular, with tightly cemented portions of low permeability, shale partings, and a lack of uniformity in lithology that has caused a retention of part of their connate waters.

The Madison limestone (Mississippian), the oldest oil-producing formation in Wyoming, yields oil in porous dolomitic portions in its upper 600–800 feet. The Embar formation, of Permian and Triassic age, yields oil in porous dolomites and in some thin sandstones.

All the productive zones crop out on the flanks of the various mountainous uplifts, and meteoric waters falling thereon migrate in the sands for long distances toward the lowest parts of the structural basins.

CHEMICAL CHANGES IN OIL-FIELD WATERS

The chemical changes that have taken place in subsurface connate sea water subsequent to deposition are complex and many are highly speculative. Two changes in particular are important; namely, the absence of the sulphate radicle and the alkaline earths in some waters, both being present in normal sea water.

The sulphate radicle and the alkaline earths are absent in the oil-field waters of the Upper Cretaceous sandstone formations, but dominate in the Embar formation, the Tensleep sandstone, and the Madison limestone. The difference in the chloride salinity between the shallower and deeper zones is undoubtedly caused by the freshening action of circulating meteoric waters in the deeper and more continuous sandstones.

According to Rogers,[4] the absence of sulphate in the oil-field waters of the San Joaquin Valley, California, is caused by its reduction to sulphide, with a corresponding formation of carbonate. In support of this widely accepted conclusion he points out that the waters in the Valley in contact with oil contain no sulphate.

After reviewing various published hypotheses concerning the change of sulphate to carbonate, Stabler[5] concludes that:

> Whether the exchange of sulphate for carbonate is purely chemical, with or without one or more catalysts, or is aided or initiated by bacteria, there can be little doubt that it takes place underground, and considerable reliance can be placed upon it for an explanation of the sulphate-free character of most waters of the Salt Creek-Teapot uplift.

In this writer's opinion, the exchange of sulphate for carbonate logically explains the sulphate-free oil-field waters of Wyoming which, when associated with oil, are largely found with paraffin-base oil. Under like conditions, the sulphate waters of the state are generally associated with intermediate or naphthene-base oils, the so-called black oils, and hydrogen sulphide is commonly present. This suggests that the active reduction of sulphate is now taking place in the more deeply buried formations.

A detailed study of many well logs has shown that lentils and beds

[4] G. Sherburne Rogers, "Chemical Relations of the Oil Field Waters in the San Joaquin Valley, California," *U. S. Geol. Survey Bull. 653* (1917).

[5] Herman Stabler, "Waters of the Salt Creek-Teapot Dome Uplift," *U. S. Geol. Survey Prof. Paper 163* (1931), pp. 51–53.

of bentonite are present in the Shannon, Frontier, and Cloverly sands and in the intervening shales. As bentonite is a hydrous silicate of alumina with base-exchange properties and will adsorb ions of higher valence, it seems likely that contact with bentonite has caused the removal of the calcium and magnesium in the water. As bentonite is not found in pre-Cretaceous formations in Wyoming, it is probable that the present deficiency of the Cretaceous period waters in calcium and magnesium can be explained in this way.

ARRANGEMENT OF ANALYSES

The analyses discussed are grouped according to their occurrence in the main structural basins, beginning at the northwest corner and trending southeastward. Fields from which water samples have been obtained are arranged in order from north to south and west to east in the basins, and the wells likewise. The main structural basins are the Big Horn Basin, Wind River Basin, Powder River Basin, Shirley Basin, Hanna Basin, Laramie Basin, and the Sweetwater Basin (Great Divide Basin). The locations of these basins and the oil and gas fields therein are shown on Figure 1.

SURFACE WATERS

Wyoming is mainly semi-arid, the average annual precipitation being about 16 inches. As a result, most of the water in the streams comes from melting snows in the high ranges.

As most of the surface waters originate in a weathered igneous terrane, they are of the primary alkaline type at and near their source, the alkaline silicates being the most soluble constituents of igneous rocks and, together with carbon dioxide from the air and plant life of the stream, giving the water primary alkalinity. Such a water contains large proportions of the sodium and bicarbonate radicles, a little chloride, some calcium and magnesium, but very little, if any, sulphate. This kind of mountain water is very dilute and seldom has a concentration of 300 parts per million total solids.

After leaving the mountains the streams flow across areas whose soil is largely derived from marine strata, with the result that the water acquires sulphate and alkaline earths until it is characterized by secondary salinity. Such a water contains considerable calcium and magnesium sulphate, besides a normal percentage of sodium chloride and bicarbonate. Seasonal variations in flow cause some changes in the content of dissolved salts, but the general characteristics of salinity and alkalinity are rather constant.

Table I shows six analyses of surface waters, and their graphs

follow. The first five of these analyses are listed in order of increasing secondary salinity. The sixth, that of Nigger Creek, shows the character of a mountain water before it runs over marine strata.

SHOSHONE RIVER

The Shoshone River is the largest tributary of the Big Horn River and drains the northwestern part of the Big Horn Basin. It rises in the Absaroka Mountains and, east of Cody, traverses a broad, rather level, flat as far as Garland. Analysis 1 was taken near the Garland oil field, March 2, 1937.

This is the lowest in secondary salinity of the five surface-water analyses. Below the Shoshone Reservoir this water is used extensively for irrigation and there acquires sulphate leached from irrigated soils. In the adjacent oil fields the river water is used in boilers, sometimes with treatment to remove permanent hardness, but often without treatment. It is also used for domestic purposes despite its rather high sulphate content. This water is easily distinguished from oil-field waters in the northern part of the Big Horn Basin by its far lower concentration.

NORTH PLATTE RIVER

The North Platte River rises in a network of mountain streams in North Park, Colorado, and drains the southeast quarter of Wyoming. As the water originates in an igneous terrane, it is characterized by primary alkalinity near its source, but a change to secondary alkalinity takes place before it reaches the Pathfinder Reservoir.

Two analyses of North Platte River water are given. Analysis 2, sampled at Fort Laramie, was published in 1911. Analysis 3 was sampled at the Pathfinder Dam spillway-valve in February, 1928, and analyzed at the Midwest laboratory of the Geological Survey. The two waters are very similar after a lapse of more than 17 years. This water is used extensively for irrigation, oil-field operations, and domestic purposes.

POPO AGIE RIVER

The Popo Agie River rises high in the Wind River Mountains and joins the Wind River to form the Big Horn River. Analysis 4 represents a sample from the Popo Agie obtained near Dallas dome, July 17, 1930, when the stream was low and clear. The water is of the secondary saline type, with an exceptionally low chloride content. This water is the lowest in concentration of the surface waters described, and is used in oil-field operations, irrigation, and for domestic purposes.

TABLE I
Surface Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
1	Shoshone River at Garland, Wyoming	--	--	--	--	856	130	104	42	395	32	--	315	5.66	5.19	3.45	8.23	0.90	--	5.17	39.58	24.26	---	36.16	9.83	90.15
2	[a]North Platte River at Ft. Laramie, Wyoming	--	--	--	--	359	28	69	18	150	19	--	150	1.20	3.40	1.50	3.10	0.50	--	2.50	26.20	33.60	---	40.20	14.70	85.30
3	North Platte River at Pathfinder, Wyoming	--	--	--	--	317	15	70	16	132	15	--	140	0.66	3.49	1.32	2.75	0.42	--	2.30	12.00	46.10	---	41.90	13.25	86.75
4	Popo Agie River, near Lander, Wyoming	--	--	--	--	204	6	36	18	102	Tr	--	85	0.24	1.79	1.48	2.12	---	--	1.39	6.84	53.56	---	39.60	---	100.00
5	Willow Creek, near Kaycee, Wyoming	--	--	--	--	940	31	200	44	572	11	--	166	1.34	9.98	3.62	11.91	0.31	--	2.72	8.96	72.84	---	18.20	2.54	97.46
6	Bigger Creek, near Casper, Wyoming	--	--	--	--	217	11	49	17	--	3	--	259	0.48	2.45	1.40	---	0.08	--	4.25	1.84	---	9.24	88.92	100.00	---

[a] From U. S. Geological Survey Water-Supply Paper 274, 1911.

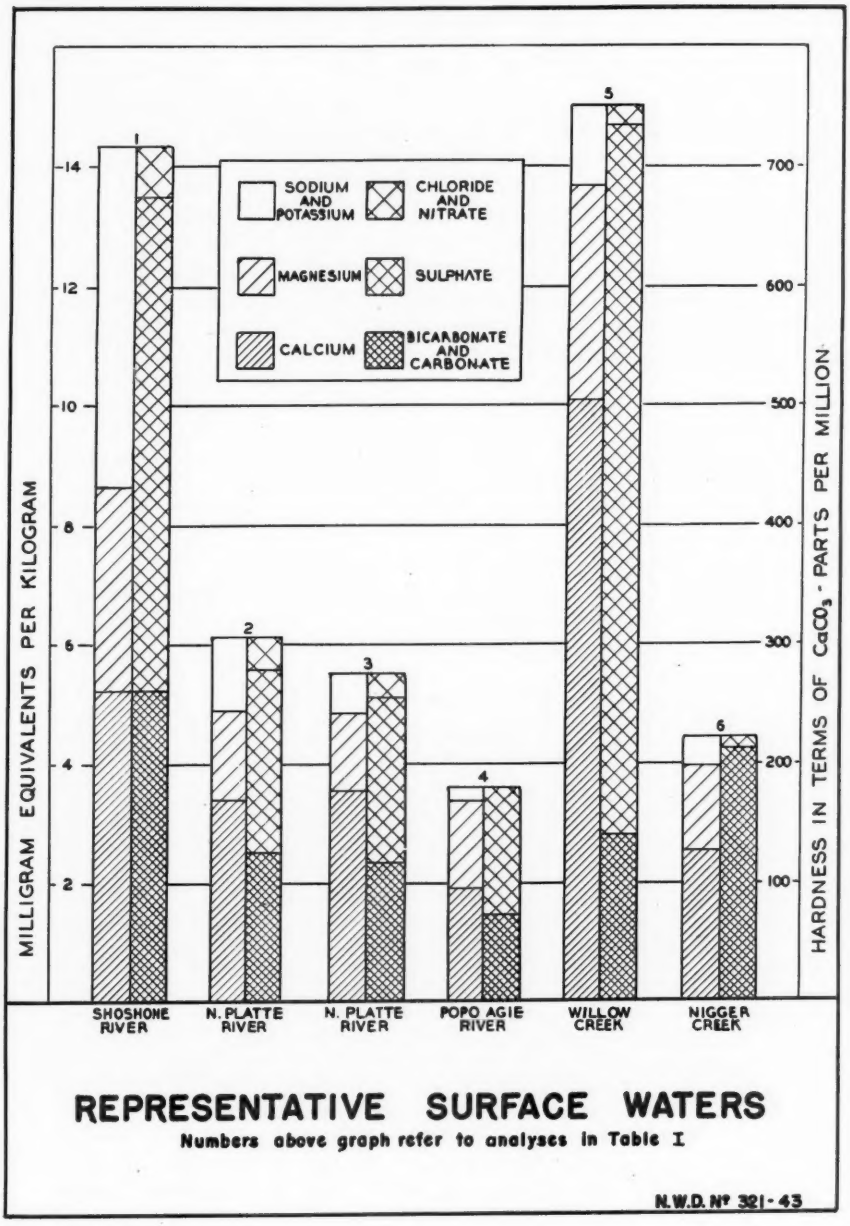

MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
14
12
10
8
6
4
2
700
600
500
400
300
200
100
1
2
3
4
5
6
SHOSHONE RIVER
N. PLATTE RIVER
N. PLATTE RIVER
POPO AGIE RIVER
WILLOW CREEK
NIGGER CREEK
REPRESENTATIVE SURFACE WATERS
Numbers above graph refer to analyses in Table I
N.W.D. Nº 321-43

FIG. 3

WILLOW CREEK

Willow Creek rises in springs in southern Johnson County. For about 2 miles below its source the water is fresh, comparatively dilute, and seemingly comes from igneous rocks. Although the stream is only a few miles long, downstream it leaches calcium sulphate from the Steele shale and the water has the character typified by the analysis.

In many respects the water of Willow Creek resembles that from the Shannon sandstone member of the Steele shale in the Salt Creek oil field, although in the latter area the surface water has had a longer period of contact with the Steele shale and has become more concentrated.

NIGGER CREEK

Nigger Creek, in eastern Natrona County, has an alkaline type of water, the bicarbonate radicle being the dominant acid radicle and calcium the dominant basic radicle. Its alkalinity is characteristically secondary, and the salinity present comes from the chloride radicle. Sulphate is absent, probably because the water has not been in contact with marine shale. Through the solvent action of carbonic acid, the snow water acquired its content of calcium, magnesium, and sodium in passing over igneous gravel and limestone.

SHANNON SANDSTONE WATERS

The Shannon sandstone member of the Steele shale, of Upper Cretaceous age, contains oil at Big Muddy, Teapot, and the Shannon pool of the Salt Creek field, but elsewhere ordinarily contains water. Water samples have been obtained from the Shannon only in that part of the Powder River Basin lying between Shawnee on the south and Billy Creek on the north, including the Salt Creek, Teapot, and Big Muddy oil fields and Burris dome. As shown in Table II, the Shannon waters are of three distinct types. At Big Muddy and Shawnee the water is characterized by high primary salinity and a small amount of secondary alkalinity. At Billy Creek primary alkalinity is prominent, whereas at Salt Creek secondary salinity and secondary alkalinity predominate. The differences in character of the Shannon waters are probably due largely to variations in the types of surface waters where the sand crops out.

POWDER RIVER BASIN

Billy Creek gas field.—The Billy Creek gas field lies only a few miles east of the Big Horn Mountains, where all formations drilled in the field crop out. The Frontier formation, the producing gas zone,

occurs at a depth of about 3,000 feet and contains some unsampled water.

The top of the Shannon sandstone member of the Steele shale is found at depths ranging from 900 to 1,300 feet and is the main water sand in the field. Representative analyses of water from the Shannon are numbered from 7 to 11, inclusive, in Table II, the analyses trending in order southeastward along the crest of the dome.

The waters of the Shannon sandstone at Billy Creek are of the primary alkaline type, being essentially a solution of sodium chloride and sodium bicarbonate. In the northern and central parts of the field the bicarbonate content is higher than the chloride, and the water is similar to the water in the First Wall Creek sand in the Salt Creek oil field. In the southern part of the field the chloride content increases and eventually is greater than the bicarbonate, the concentration increasing at the same time. As this water has a concentration ranging from 2,000 to 3,000 parts per million, it is the most dilute of all Shannon waters analyzed.

The source of the artesian water in the Shannon sandstone in the Billy Creek field is, undoubtedly, the near-by Big Horn Mountains, where waters from melting snow and springs enter the outcrop of the sandstone and the fresh, sulphate-free water moving downdip leaches sodium chloride and bicarbonate. As the concentration and chloride content increase progressively southward, it is thought that the water movement in the sandstone is north and east. The relatively dilute concentration of the water as compared with Shannon waters elsewhere suggests a rather rapid movement in the sandstone.

Owing to the high content of dissolved salts, the Shannon water in this vicinity is valueless for irrigation or domestic purposes; in fact, it is not recommended for use in boilers, though similar waters have been used elsewhere.

Burris dome.—Burris dome lies on the northern end of the Salt Creek uplift. Two wells have been drilled on the structure, one having been abandoned at a depth of 900 feet and the other at 3,355 feet in the Shannon sandstone. The water in the Shannon sandstone is similar to those in that sand in the Salt Creek oil field, as shown by comparing analyses 12 and 13 of Burris dome with analyses 14 and 15 of the Salt Creek field.

Salt Creek area.—The Salt Creek area, which includes Burris dome on the north, the Salt Creek oil field in the middle, and the Teapot dome field on the south, is about 30 miles long and 5 miles wide. The Shannon normally consists of two sandstones separated by dark clay containing concretions of greenish sandstone. The upper part of the

TABLE II
SHANNON SANDSTONE WATERS

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
											POWDER RIVER BASIN															
7	Billy Creek	- -	17	48N	82W	2,624	1,079	- -	- -	- -	893	30	1,225	46.94	- - -	- - -	- - -	25.19	1.67	20.08	53.66	- - -	46.34	- - -	100.00	- - -
8	Billy Creek	2	17	48N	82W	2,132	889	- -	- -	- -	534	30	1,380	38.68	- - -	- - -	- - -	15.06	1.00	22.62	38.94	- - -	61.06	- - -	100.00	- - -
9	Billy Creek	1	17	48N	82W	2,672	1,100	- -	- -	- -	885	tr	1,395	47.84	- - -	- - -	- - -	24.97	- - -	22.87	52.20	- - -	47.80	- - -	100.00	- - -
10	Billy Creek	2	21	48N	82W	3,269	1,323	- -	- -	- -	1,427	37	980	57.54	- - -	- - -	- - -	40.25	1.23	16.06	59.54	- - -	30.06	- - -	100.00	- - -
11	Billy Creek	1	28	48N	82W	3,256	1,321	- -	- -	- -	1,372	tr	1,145	57.47	- - -	- - -	- - -	38.70	- - -	18.77	67.34	- - -	32.66	- - -	100.00	- - -
12	Burris Dome	- -	28	42N	79W	4,521	1,312	104	44	2,680	tr	- - -	368	57.04	5.18	3.62	59.80	- - -	- - -	6.04	86.64	4.24	- - -	9.12	- - -	100.00
13	Burris Dome	- -	28	42N	79W	3,940	1,265	31	8	2,420	71	tr	295	55.02	1.55	0.66	50.39	2.00	- - -	4.84	91.54	- - -	4.60	3.86	3.82	96.18
14	Salt Creek	1A	18	40N	78W	2,874	407	126	301	1,527	26	- -	990	17.71	6.29	24.75	31.79	0.73	- - -	16.23	36.32	30.38	- - -	33.30	2.23	97.77
15	Salt Creek	2	19	40N	78W	5,009	1,174	175	227	2,895	52	- -	1,070	51.06	8.73	18.67	59.45	1.47	- - -	17.54	65.08	12.96	- - -	22.36	2.41	97.59
16	Salt Creek	25-AB	19	40N	78W	4,157	853	172	263	2,272	29	- -	1,160	36.92	8.58	21.63	47.30	0.82	- - -	19.01	55.00	16.66	- - -	28.32	1.70	98.30
17	Salt Creek	25-AB	19	40N	78W	4,133	876	169	282	2,263	22	- -	1,140	38.09	8.43	19.90	47.11	0.62	- - -	18.69	57.34	14.52	- - -	28.14	1.31	98.69
18	Salt Creek	25-AB	19	40N	78W	4,158	875	168	290	2,270	34	- -	1,140	37.97	8.38	20.56	47.26	0.96	- - -	18.69	56.76	15.32	- - -	27.92	2.01	97.99
19	Salt Creek	25-AB	19	40N	78W	3,961	660	213	309	2,225	21	- -	1,085	28.65	10.63	25.41	46.32	0.99	- - -	17.78	44.28	28.24	- - -	27.48	1.27	98.73
20	Salt Creek		24	39N	79W	4,335	1,588	- -	- -	1,780	28	tr	1,905	69.10	- - -	- - -	37.06	0.82	- - -	31.22	94.82	- - -	45.18	- - -	2.15	97.85
21	Salt Creek		30	39N	78W	5,715	1,666	37	218	2,626	302	79	1,600	72.26	1.85	17.93	54.67	8.52	2.63	26.22	68.66	- - -	9.86	21.48	13.49	86.51
22	Salt Creek	30	32	40N	79W	3,625	467	253	385	2,093	42	- -	905	20.23	12.63	26.73	43.58	1.18	- - -	14.83	33.94	41.18	- - -	24.88	2.65	97.35
23	Salt Creek	4	33	40N	79W	3,373	1,139	6	- -	1,944	20	18	500	49.52	0.30	- - -	40.46	0.56	0.60	8.20	82.14	- - -	17.16	0.70	3.00	97.00
24	West Salt Creek	1	15	39N	79W	4,435	1,557	- -	- -	2,219	86	136	885	67.73	- - -	- - -	46.20	2.43	4.60	14.50	71.80	- - -	28.20	- - -	4.99	95.01
25	East Teapot Dome	1	12	39N	78W	5,937	1,690	70	38	3,713	50	- -	440	79.31	3.49	3.13	77.31	1.41	- - -	7.21	91.72	- - -	0.54	7.74	1.50	98.50
26	Big Muddy	10	4	33N	76W	14,649	5,556	130	48	95	8,558	- -	533	241.67	6.49	3.95	1.98	241.40	- - -	8.73	99.86	0.68	- - -	3.46	99.18	0.82
27	Big Muddy	25	9	33N	76W	9,474	3,657	43	30	- -	5,415	- -	670	159.10	2.15	2.47	- - -	152.74	- - -	10.98	93.30	- - -	3.88	2.82	100.00	- - -
28	Big Muddy	14	8	33N	76W	13,090	4,989	77	49	- -	7,724	- -	450	217.12	3.84	4.03	- - -	217.60	- - -	7.38	96.90	0.22	- - -	3.28	100.00	- - -
29	Big Muddy	3	9	33N	76W	13,133	5,044	78	38	- -	7,668	- -	620	219.43	3.89	3.14	- - -	216.30	- - -	10.16	99.52	- - -	1.38	3.10	100.00	- - -
30	Shannon	1	16	32N	69W	9,520	3,768	- -	- -	32	5,356	229	275	163.90	- - -	- - -	0.67	151.08	7.64	4.51	92.58	- - -	7.42	- - -	99.56	0.44

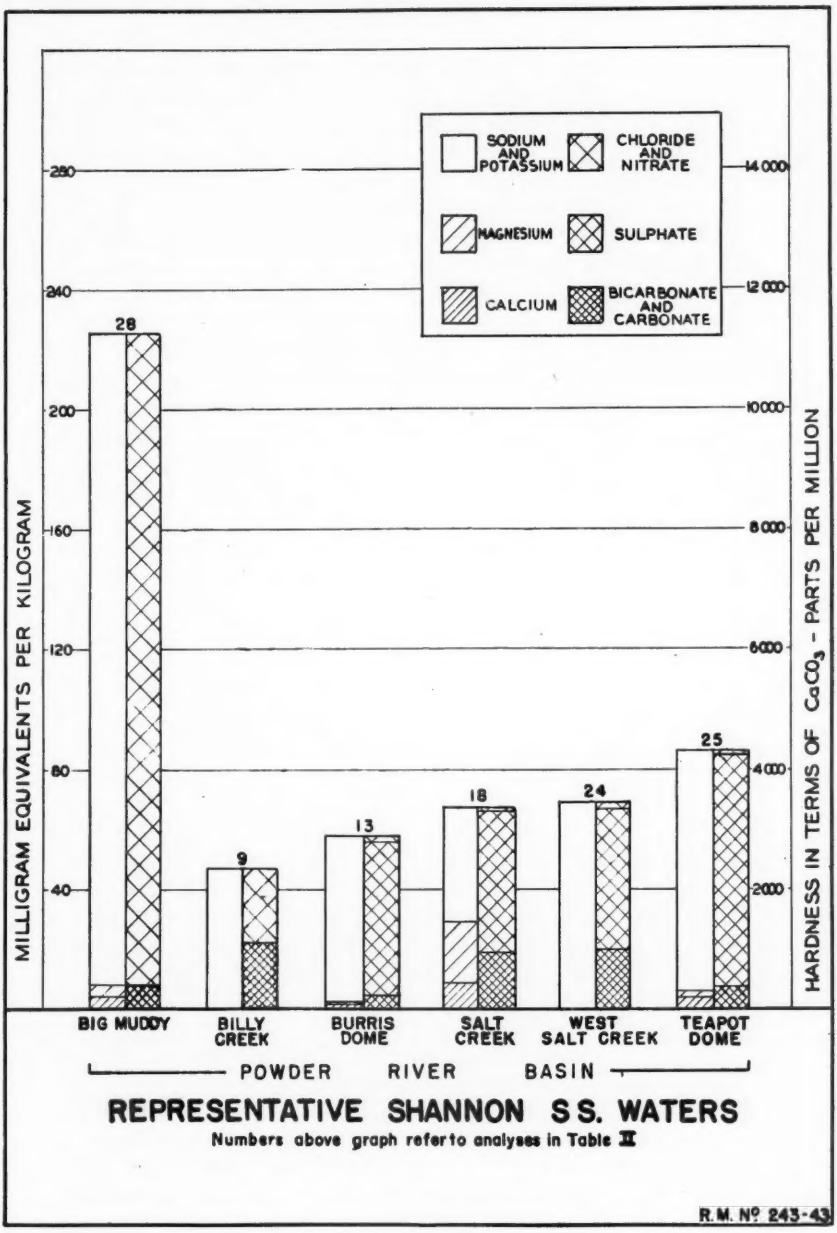

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
280
240
200
160
120
80
40
14 000
12 000
10000
8000
6000
4000
2000
28
9
13
18
24
25
BIG MUDDY
BILLY CREEK
BURRIS DOME
SALT CREEK
WEST SALT CREEK
TEAPOT DOME
POWDER RIVER BASIN
REPRESENTATIVE SHANNON S.S. WATERS
Numbers above graph refer to analyses in Table II
R.M. No. 243-43

FIG. 4

Shannon forms an escarpment on the east and west sides of the Salt Creek uplift, dipping sharply west and rather gently on the east flank. It is about 135 feet thick and ordinarily contains water, though it contained some oil in the Shannon pool, between Burris dome and the Salt Creek field, and in Teapot dome.

Fourteen analyses of Shannon waters in the Salt Creek area are given in Table II. The waters in analyses 14–24 came from depths of 100–200 feet on the edges of the Salt Creek field, but in the eastern part of Teapot dome (analysis 25) the top of the sandstone was found at a depth of approximately 1,000 feet.

The Shannon waters in the Salt Creek area are essentially saline waters with the salinity caused almost entirely by the sulphate radicle. The chloride is negligible, and the bicarbonate rather erratic, ranging from 300 to 2,000 parts per million. Total solids vary from 3,000 to 6,000 parts per million. Although the water is subject to some variation because of rainfall, it is always distinguished by its higher sulphate content.

Many analyses of Shannon waters in the Salt Creek area show neither calcium nor magnesium, and the predominating soluble constituent is sodium sulphate; in fact, in the early history of the Salt Creek field the presence of sodium sulphate was the criterion for distinguishing Shannon water from other subsurface waters. In 1935, however, Shannon waters appeared carrying notable amounts of the alkaline earths, as shown in analyses 14–19, Table II. As these analyses were very closely correlative with analyses of surface waters in the Salt Creek field, it became necessary to explain the absence of the alkaline earths in other Shannon waters.

The surface formation in a large part of the Salt Creek area is the gypsum-bearing Steele shale. Three small creeks, Teapot Creek, Castle Creek, and Salt Creek, drain the area, and their waters leach calcium and magnesium from the Steele shale, with the result that the surface water of the area has an exceptionally high secondary salinity. This water is the source of the Shannon water, it is believed. However, part of its calcium and magnesium content may be lost in the sand by precipitation as carbonate or by base exchange; that is, the exchange of calcium and magnesium for sodium through the action of base-exchange silicates.

The action of base exchange may be illustrated by the common zeolite water-softening process, zeolites being hydrous silicates of alumina, with calcium, magnesium, and the alkalies. When water containing calcium and magnesium contacts zeolites the sodium in the zeolite is exchanged for the calcium and magnesium in the water,

the result being soft water. When the sodium and potassium in the zeolites are exhausted, the zeolites are rejuvenated by treating with a strong brine solution, the reverse action taking place.

Bentonite, a hydrous silicate of alumina with base-exchange properties, occurs at the surface, between subsurface sands, and in thin layers in the Upper Cretaceous sandstones of the Salt Creek area. It is believed, therefore, that surface water highly impregnated with calcium and magnesium comes in contact with the bentonite and exchanges its calcium and magnesium for sodium, the result being a water similar to analyses 20 and 23.

Shannon water containing calcium and magnesium is found at relatively shallow depths. Where the sand is at greater depths in the Salt Creek area, sodium sulphate water is usually found, as would be expected under the theory of base-exchange action.

The only use for Shannon water in the Salt Creek area is in boilers.

Big Muddy oil field.—The surface formation in the Big Muddy oil field is the Steele shale. The top of the Shannon sandstone member occurs at a depth of about 900 feet and consists of alternating lenses of buff to gray sandstone and sandy shale about 30 feet thick and carrying both oil and water.

The Shannon water is of the primary saline type, the salinity being caused by chlorides. Furthermore, it is the highest concentrated Shannon water so far analyzed, having 10,000–15,000 parts per million total solids. Calcium and magnesium are sparingly present, and the bicarbonate radicle is relatively low. In general, the water is a solution of sodium chloride, with small amounts of sodium, calcium, and magnesium bicarbonates. Sulphates are absent, except in those few cases where possible contamination with either surface or drilling water has occurred. The water probably entered the sand at its outcrop in the mountains a short distance south.

The Shannon water is more concentrated and contains more chloride and less bicarbonate than that in the lower part of the Frontier formation in the field. Furthermore, it is distinguished from Lakota water by its much higher concentration and by the fact that the Lakota water contains sulphate. Because of its high salinity, it is not used in the Big Muddy field.

Shawnee area.—In the Shawnee area the top of the Shannon sandstone was found at a depth of 4,043 feet in one well. The Shannon water in this well is similar to the Shannon water at Big Muddy. The carbonate present in the analysis in Table II resulted from exposure of the sample and the consequent change of part of the bicarbonate to carbonate. The calcium and magnesium, if present, would com-

TABLE III
Frontier Formation Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
														BIG HORN BASIN												
31	Elk Basin	2	NE 31	56N	99W	9,258	3,676	21	tr	- - -	4,762	37	1,550	159.91	1.05	- - -	- - -	134.33	1.23	25.40	83.46	- - -	15.88	0.66	100.00	- - -
32	Elk Basin	1	SW 32	56N	99W	10,058	3,980	28	tr	tr	5,300	- -	1,525	173.11	1.40	- - -	- - -	149.51	- - -	25.00	85.68	- - -	13.52	0.80	100.00	- - -
33	Elk Basin	1	SW 32	56N	99W	10,131	4,000	39	tr	76	5,200	- -	1,660	173.51	1.95	- - -	1.58	146.68	- - -	27.20	84.60	- - -	14.20	1.20	98.94	1.06
34	Elk Basin	3	SW 32	56N	99W	9,784	3,867	24	tr	- - -	5,275	- -	1,257	168.21	1.20	- - -	- - -	148.81	- - -	20.60	87.84	- - -	11.46	0.70	100.00	- - -
35	Elk Basin	5	SW 32	56N	99W	9,096	3,604	20	tr	- - -	4,800	tr	1,366	156.80	1.00	- - -	- - -	135.41	- - -	22.39	85.82	- - -	13.54	0.64	100.00	- - -
36	*Elk Basin			56N	99W	8,145	3,326	21	16	- - -	4,260	66	1,520	145.00	1.10	1.30	- - -	120.00	2.20	25.20	81.40	- - -	17.00	1.60	100.00	- - -
37	Garland	1	NE 15	55N	97W	10,901	4,575	- -	- -	- - -	2,305	185	7,800	199.02	- - -	- - -	- - -	65.02	6.16	127.84	32.66	- - -	67.34	- - -	100.00	- - -
38	Oregon Basin	1	SW 20	52N	100W	1,473	606	18	4	tr	120	- -	1,475	26.33	0.90	0.33	- - -	3.38	- - -	24.18	12.30	- - -	83.30	4.40	100.00	- - -
39	Oregon Basin	1	SW 20	52N	100W	1,491	642	- -	- -	- - -	92	37	1,465	27.84	- - -	- - -	- - -	2.60	1.23	24.01	9.34	- - -	90.66	- - -	100.00	- - -
40	Oregon Basin	3-W	NE 7	51N	100W	1,412	606	- -	- -	- - -	105	72	1,280	26.34	- - -	- - -	- - -	2.96	2.40	20.98	11.24	- - -	88.76	- - -	100.00	- - -
41	Oregon Basin		19	51N	100W	1,800	746	- -	- -	169	97	120	1,355	32.47	- - -	- - -	3.52	2.74	4.00	22.21	19.28	- - -	80.72	- - -	43.77	56.23
42	Oregon Basin	1	NW 23	51N	100W	1,559	666	- -	- -	- - -	150	79	1,350	28.99	- - -	- - -	- - -	4.23	2.63	22.13	14.60	- - -	85.40	- - -	100.00	- - -
43	Oregon Basin	1	NW 33	51N	100W	1,688	701	- -	- -	- - -	488	- -	1,015	30.40	- - -	- - -	- - -	13.76	- - -	16.64	45.26	- - -	54.74	- - -	100.00	- - -
44	Oregon Basin	1	SE 5	51N	100W	1,502	647	- -	- -	- - -	71	80	1,431	28.14	- - -	- - -	- - -	2.00	2.67	23.47	7.10	- - -	92.90	- - -	100.00	- - -
45	Skelton Dome	1	SW 23	45N	100W	1,430	577	32	tr	12	100	84	1,270	25.09	1.60	- - -	0.25	2.82	2.80	20.82	11.40	- - -	82.60	6.00	93.00	7.00
46	Reiber Dome	1		19	45N	92W	2,724	1,105	- -	- -	244	551	133	1,405	48.08	- - -	- - -	5.08	15.54	4.43	23.03	42.88	- - -	57.12	- - -	75.37	24.63
														WIND RIVER BASIN												
47	*Pilot Butte	8	NW 27	3N	1W	4,383	1,698	24	57	- -	1,395	- -	2,472	73.90	1.20	4.70	- - -	39.30	- - -	40.30	49.30	- - -	43.30	7.40	100.00	- - -
48	Alkali Butte	1	NW 1	33N	95W	13,776	5,576	- -	- -	29	5,929	tr	4,560	242.58	- - -	- - -	0.60	167.25	- - -	74.73	69.20	- - -	30.80	- - -	99.65	0.35
49	Alkali Butte	1	SW 36	34N	95W	6,028	2,438	- -	- -	19	2,609	217	1,515	106.06	- - -	- - -	0.40	73.59	7.24	24.83	69.76	- - -	30.24	- - -	99.46	0.54
50	Big Sand Draw	2	NE 9	32N	95W	5,640	2,252	16	tr	26	2,600	tr	1,518	97.96	0.80	- - -	0.54	73.34	- - -	24.88	74.80	- - -	25.20	0.80	99.27	0.73
51	Big Sand Draw	2	NE 9	32N	95W	5,982	2,384	18	tr	50	2,750	tr	1,586	103.71	0.90	- - -	1.04	77.57	- - -	25.99	75.60	- - -	23.60	0.80	98.68	1.32
														SHOSHONE BASIN												
52	North Baxter Basin		12	19N	104W	28,626	10,879	222	125	- -	16,667	- -	1,490	473.22	11.08	10.28	- - -	470.15	- - -	24.43	95.06	- - -	0.62	4.32	100.00	- - -
53	Middle Baxter Basin	1	NE 18	18N	103W	50,985	20,010	74	112	- -	27,900	tr	5,875	870.38	3.69	9.21	- - -	787.00	- - -	96.28	89.10	- - -	9.44	1.46	100.00	- - -
54	Middle Baxter Basin	1	NE 18	18N	103W	50,348	19,750	78	107	- -	27,500	- -	5,925	860.13	3.89	8.80	- - -	775.72	- - -	97.10	88.88	- - -	9.66	1.46	100.00	- - -
55	Middle Baxter Basin	1	NW 30	18N	103W	32,518	12,856	48	57	41	15,692	- -	7,450	559.22	2.40	2.85	0.85	441.51	- - -	122.11	78.36	- - -	20.72	0.92	99.82	0.18
56	Middle Baxter Basin	1	NW 30	18N	103W	23,952	9,508	17	46	91	11,700	180	4,900	413.61	0.85	3.78	1.89	330.04	6.00	80.31	79.36	- - -	19.54	1.10	99.44	0.56
57	South Baxter Basin	1		2	17N	104W	21,515	8,790	- -	- -	- -	8,150	1,047	7,175	382.36	- - -	- - -	- - -	229.89	34.90	117.99	60.12	- - -	39.88	- - -	100.00	- - -
58	Lost Soldier	42		3	26N	90W	12,038	4,901	tr	- -	18	5,000	tr	4,310	212.06	- - -	- - -	0.37	141.04	- - -	70.64	66.68	- - -	33.32	- - -	99.73	0.27
59	Lost Soldier	16A		11	26N	90W	13,263	5,376	36	tr	- -	5,100	- -	5,595	233.77	1.80	- - -	- - -	143.86	- - -	91.70	61.24	- - -	37.96	0.80	100.00	- - -
60	Eight Mile Lake	1	SE 34	19N	88W	1,209	522	- -	- -	tr	49	50	1,195	22.64	- - -	- - -	- - -	1.38	1.67	19.99	6.10	- - -	93.90	- - -	100.00	- - -

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
														SUBSURFACE BASIN (Continued from Page 1)												
61	Sherard	1	NW 26	25N	89W	2,471	1,084	--	--	--	140	72	2,430	46.18	---	---	---	3.95	2.40	39.83	8.56	---	91.44	---	100.00	---
62	Bell Springs	1	NW 30	24N	88W	4,804	2,002	--	--	--																
63	Bell Springs	2	SE 6	23N	88W	2,612	1,101	--	--	--	1,257	--	3,150	87.09	---	---	---	35.46	---	51.63	40.72	---	59.28	---	100.00	---
64	Bell Springs	1	SW 8	23N	88W	3,775	1,591	--	--	--	503	--	2,050	47.78	---	---	---	14.18	---	33.60	29.68	---	70.32	---	100.00	---
											738	--	2,940	69.01	---	---	---	20.82	---	48.19	30.16	---	69.84	---	100.00	---
65	O'Brien Springs	1	SE 35	25N	88W	3,142	1,326	--	--	--	587	--	2,500	57.52	---	---	---	16.55	---	40.97	28.78	---	71.22	---	100.00	---
												POISON SPITHER AREA														
66	Lex		35	37N	86W	6,665	2,650	29	Tr	--	3,150	Tr	1,700	115.26	1.45	---	---	88.85	---	27.86	76.12	---	22.64	1.24	100.00	---
														POTTERS RIVER BASIN												
	Salt Creek:																									
67	First Wall Creek Sand	25A	NW 12	40N	79W	5,311	2,248	6	Tr	--																
68	do	29A	NE 12	40N	79W	4,177	1,776	--	--	--	750	320	4,040	97.75	0.30	---	---	21.16	10.67	66.22	21.96	---	76.14	0.30	100.00	---
69	do	25	NE 18	40N	79W	3,965	1,684	12	5	15	550	110	3,540	77.20	---	---	---	15.51	3.67	58.02	20.00	---	80.00	---	100.00	---
70	do	36Aa	NE 10	40N	79W	2,401	1,045	Tr	--	18	420	Tr	3,760	72.78	0.60	0.49	0.31	11.85	---	61.63	16.82	---	82.28	1.20	97.46	2.54
71	do	31A	NW 7	40N	78W	3,807	1,636	--	--	--	160	276	1,915	45.47	---	---	0.37	4.51	9.20	31.35	10.60	---	89.40	---	92.45	7.55
72	do	4	18	40N	78W	3,337	1,411	Tr	--	--	425	Tr	3,550	70.17	---	---	---	11.99	---	58.18	17.08	---	82.92	---	100.00	---
73	do	15	NW 23	40N	79W	3,499	1,454	Tr	--	64	400	115	2,740	61.36	---	---	1.33	11.29	3.83	44.91	20.54	---	79.46	---	91.67	8.33
74	do	5	NE 23	40N	79W	3,769	1,589	Tr	--	Tr	700	80	2,490	63.22	---	---	---	19.74	2.67	40.81	31.30	---	68.70	---	100.00	---
75	do	3	NW 23	40N	79W	3,529	1,491	Tr	--	--	550	Tr	3,010	69.08	---	---	---	19.75	---	49.33	28.60	---	71.40	---	100.00	---
76	do	15	SW 23	40N	79W	3,731	1,582	Tr	--	Tr	550	Tr	3,010	64.84	---	---	---	15.51	---	49.33	24.00	---	76.00	---	100.00	---
77	do	2	SE 23	40N	79W	8,130	3,331	Tr	--	--	2,950	Tr	3,250	68.78	---	---	---	15.51	---	53.27	22.70	---	77.30	---	100.00	---
78	do	7	SE 23	40N	78W	5,587	2,311	Tr	--	--	1,700	Tr	3,760	144.84	---	---	---	83.21	---	61.63	57.50	---	42.50	---	100.00	---
79	do	6	NW 24	40N	78W	9,586	3,897	Tr	--	--	4,200	Tr	3,220	100.50	---	---	---	47.95	---	52.55	47.80	---	52.20	---	100.00	---
80	do	23A	SE 19	40N	78W	3,386	1,420	Tr	--	Tr	700	Tr	3,110	169.44	---	---	---	118.47	---	50.97	70.00	---	30.00	---	100.00	---
81	do	23A	SE 19	40N	78W	3,702	1,565	Tr	--	34	700	120	2,330	61.74	---	---	---	19.75	4.00	38.19	29.60	---	70.40	---	100.00	---
82	do	7	NW 28	40N	79W	9,605	3,923	--	--	20	3,602	25	4,137	68.64	---	---	0.71	12.00	7.23	48.70	18.54	---	81.46	---	94.49	5.51
83	do	18	NW 25	40N	79W	8,777	3,641	Tr	--	Tr	2,500	241	4,870	170.67	---	---	0.42	101.58	0.83	67.84	59.76	---	40.24	---	99.60	0.40
84	do	4	NE 29	40N	79W	7,330	3,081	Tr	--	Tr	1,300	264	5,460	158.37	---	---	---	70.52	8.03	79.82	44.60	---	55.40	---	100.00	---
85	do	22A	NE 30	40N	78W	1,693	701	--	--	Tr	500	--	1,000	134.96	---	---	---	36.67	8.80	89.49	27.30	---	72.70	---	100.00	---
86	do		NW 29	40N	78W	2,819	1,201	Tr	--	Tr	340	Tr	2,600	30.49	---	---	---	14.10	---	16.39	46.36	---	53.64	---	100.00	---
87	do	33A	SW 29	40N	78W	3,294	1,376	Tr	--	23	356	127	2,869	52.20	---	---	---	9.59	---	42.61	18.32	---	81.68	---	100.00	---
88	do	3	SE 34	40N	79W	4,489	1,848	Tr	--	--	1,500	Tr	2,320	61.68	---	---	0.49	9.91	4.23	47.05	16.86	---	83.14	---	95.26	4.74
89	do	25	NE 35	40N	79W	9,784	4,026	Tr	--	Tr	3,300	196	4,640	80.33	---	---	---	42.31	---	38.02	52.60	---	47.40	---	100.00	---
90	do	16	SE 35	40N	79W	13,180	5,321	Tr	--	12	5,940	132	3,610	175.00	---	---	---	53.09	6.52	75.39	54.14	---	45.86	---	100.00	---
91	do	18	NW 36	40N	79W	9,167	3,738	Tr	--	Tr	3,600	Tr	3,710	231.38	---	---	0.25	167.56	4.40	59.17	72.50	---	27.50	---	99.86	0.14
92	do	29Az	NE 32	40N	78W	2,017	835	Tr	--	Tr	600	36	1,110	160.52	---	---	---	101.55	---	60.97	62.60	---	37.40	---	100.00	---
93	do	1	NW 3	39N	79W	1,832	778	Tr	--	Tr	250	Tr	1,635	36.31	---	---	---	16.92	1.20	18.19	46.64	---	53.36	---	100.00	---
94	do	4	NW 5	38N	78W	2,762	1,143	Tr	--	Tr	840	Tr	1,585	33.85	---	---	---	7.05	---	26.80	21.08	---	78.92	---	100.00	---
95	do	17	SE 2	39N	79W	6,020	2,549	Tr	--	48	775	Tr	5,385	49.67	---	---	---	23.68	---	25.98	47.72	---	52.28	---	100.00	---
96	do	4	NW 5	39N	78W	2,779	1,143	--	--	Tr	940	Tr	1,425	111.12	---	---	1.00	21.86	---	88.26	20.50	---	79.50	---	95.61	4.39
97	do	13	NW 5	39N	78W	4,490	1,874	24	--	--	904	509	2,395	49.70	---	---	---	26.51	---	23.19	53.50	---	46.50	---	100.00	---
98	do	18A	NW 5	39N	78W	4,268	1,822	--	--	--	850	108	3,840	80.52	1.20	---	---	25.49	16.95	39.28	31.20	---	67.32	1.48	100.00	---
99	do	1	NE 10	39N	79W	3,775	1,553	12	13	37	546	255	2,762	79.23	---	---	---	12.69	3.60	62.94	16.10	---	83.90	---	100.00	---
														67.50	0.60	1.07	0.77	14.60	8.50	45.30	22.22	---	75.36	2.42	94.96	5.04

TABLE III

FRONTIER FORMATION WATERS (*Continued*)

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
	Salt Creek (Continued):										POWDER RIVER BASIN (Continued from Page 2)														
100	First Wall Creek Sand	3	NE 10	39N	79W	3,204	1,372	- -	- -	- -	240	92	3,050	59.98	- - -	- - -	- - -	6.77	3.20	49.99	11.30	- - -	88.70	- - -	100.00	- - -
101	do	21A	SW 11	39N	79W	2,202	942	- -	- -	Tr	200	160	1,830	40.97	- - -	- - -	- - -	5.64	5.33	29.99	13.60	- - -	86.40	- - -	100.00	- - -
102	do	1A	SE 11	39N	79W	2,353	994	Tr	- -	20	220	106	2,099	43.92	- - -	- - -	0.42	6.20	3.53	33.77	15.08	- - -	84.92	- - -	93.64	6.36
103	do	3	SE 11	39N	79W	2,351	1,004	- -	- -	- -	238	108	2,035	43.66	- - -	- - -	- - -	6.71	3.60	33.35	16.38	- - -	84.62	- - -	100.00	- - -
104	do	3	SE 16	39N	78W	1,984	821	- -	- -	- -	200	90	1,775	37.73	- - -	- - -	- - -	5.64	3.00	29.09	14.94	- - -	85.06	- - -	100.00	- - -
105	do	1	NW 16	39N	78W	2,431	1,033	Tr	- -	- -	350	89	1,950	44.80	- - -	- - -	- - -	9.87	2.97	31.96	22.04	- - -	77.96	- - -	100.00	- - -
106	do	M1	NW 16	39N	78W	2,394	1,016	- -	- -	- -	310	120	1,925	44.29	- - -	- - -	- - -	8.74	4.00	31.55	19.72	- - -	80.28	- - -	100.00	- - -
107	do	7A	NW 16	39N	78W	1,670	791	Tr	- -	- -	300	36	1,510	34.41	- - -	- - -	- - -	8.46	1.20	24.75	24.64	- - -	75.36	- - -	100.00	- - -
108	Second Wall Creek Sand	36A	SE 2	40N	79W	15,696	6,244	- -	- -	879	5,296	- -	6,455	372.78	- - -	- - -	18.30	148.55	- - -	105.90	61.18	- - -	38.82	- - -	89.02	10.98
109	do	36A	NW 11	40N	79W	14,141	5,765	- -	- -	- -	5,524	Tr	5,600	250.87	- - -	- - -	- - -	155.82	- - -	95.05	62.12	- - -	37.88	- - -	100.00	- - -
110	do	31A	NE 11	40N	79W	15,640	6,423	- -	- -	- -	5,429	370	6,950	279.38	- - -	- - -	- - -	153.14	12.33	113.91	54.82	- - -	45.18	- - -	100.00	- - -
111	do	16A	SW 11	40N	79W	14,966	6,122	- -	- -	- -	5,548	- -	6,700	266.30	- - -	- - -	- - -	156.49	- - -	109.81	58.76	- - -	41.24	- - -	100.00	- - -
112	do	19A	NW 12	40N	79W	14,764	6,008	- -	- -	- -	5,953	Tr	5,700	261.34	- - -	- - -	- - -	167.93	- - -	93.41	64.26	- - -	35.74	- - -	100.00	- - -
113	do	29A	NE 12	40N	79W	14,323	5,823	- -	- -	- -	5,857	270	6,825	253.30	- - -	- - -	- - -	165.22	9.00	79.08	65.22	- - -	34.78	- - -	100.00	- - -
114	do	30A	NE 12	40N	79W	14,346	5,850	- -	- -	- -	5,405	418	6,375	254.48	- - -	- - -	- - -	152.46	13.93	85.09	59.90	- - -	40.10	- - -	100.00	- - -
115	do	32A	NE 12	40N	79W	13,936	5,690	- -	- -	- -	5,333	418	6,275	247.53	- - -	- - -	- - -	150.43	13.93	83.17	60.78	- - -	39.22	- - -	100.00	- - -
116	do	33A	NE 12	40N	79W	13,819	5,623	Tr	- -	- -	5,900	Tr	5,280	244.50	- - -	- - -	- - -	157.96	- - -	86.54	64.50	- - -	35.50	- - -	100.00	- - -
117	do	4A	SE 12	40N	79W	14,222	5,822	- -	- -	- -	5,214	248	6,975	253.26	- - -	- - -	- - -	147.07	8.27	97.92	58.08	- - -	41.92	- - -	100.00	- - -
118	do	36A	SE 12	40N	79W	14,471	5,910	- -	- -	- -	5,500	Tr	6,225	257.17	- - -	- - -	- - -	155.14	- - -	102.03	60.32	- - -	39.68	- - -	100.00	- - -
119	do	16A	NE 15	40N	79W	7,985	3,380	- -	- -	- -	1,262	590	5,600	147.04	- - -	- - -	- - -	35.60	19.67	91.77	24.22	- - -	75.78	- - -	100.00	- - -
120	do	33A	NE 15	40N	79W	8,632	3,667	- -	- -	- -	1,167	590	6,525	159.53	- - -	- - -	- - -	32.92	19.67	106.94	20.64	- - -	79.36	- - -	100.00	- - -
121	do	19A	SE 15	40N	79W	9,540	4,060	- -	- -	Tr	1,350	- -	6,420	176.08	- - -	- - -	- - -	38.08	- - -	138.00	21.60	- - -	78.40	- - -	100.00	- - -
122	do	3	NW 16	40N	78W	13,517	5,456	8	- -	- -	5,988	Tr	6,200	237.35	0.40	- - -	- - -	168.91	- - -	68.84	71.04	- - -	28.80	0.16	100.00	- - -
123	do	2A	SE 16	40N	78W	15,893	6,492	- -	- -	- -	6,047	60	4,700	282.39	- - -	- - -	- - -	170.58	2.00	109.81	61.10	- - -	38.90	- - -	100.00	- - -
124	do	1A	SE 22	40N	79W	12,583	5,173	Tr	- -	- -	4,286	248	6,850	225.04	- - -	- - -	- - -	120.90	8.27	95.87	53.72	- - -	46.28	- - -	100.00	- - -
125	do	19A	NE 24	40N	79W	9,615	3,908	12	- -	85	2,250	360	6,100	169.95	0.60	- - -	1.77	63.47	5.33	99.98	38.26	- - -	61.58	0.34	97.33	2.67
126	do	1	NE 19	40N	78W	11,173	4,504	Tr	- -	- -	5,165	Tr	3,060	195.85	- - -	- - -	- - -	145.69	- - -	50.15	74.36	- - -	25.64	- - -	100.00	- - -
127	do	27	NE 19	40N	78W	12,430	5,035	- -	- -	- -	5,367	120	3,900	219.03	- - -	- - -	- - -	151.11	4.00	63.92	74.90	- - -	25.10	- - -	100.00	- - -
128	do	25A	SE 19	40N	78W	12,273	4,945	Tr	- -	Tr	5,700	Tr	3,310	215.04	- - -	- - -	- - -	160.79	- - -	54.25	74.80	- - -	25.20	- - -	100.00	- - -
129	do	26A	SE 19	40N	78W	12,529	5,082	- -	- -	- -	5,295	180	4,010	221.08	- - -	- - -	- - -	149.36	6.00	65.72	67.56	- - -	32.44	- - -	100.00	- - -
130	do	2	NW 27	40N	79W	10,003	4,065	- -	- -	- -	4,119	295	3,100	176.84	- - -	- - -	- - -	116.19	9.84	50.81	65.70	- - -	34.30	- - -	100.00	- - -
131	do	9	NW 27	40N	79W	13,369	5,525	- -	- -	- -	4,139	Tr	7,575	240.34	- - -	- - -	- - -	116.19	- - -	124.15	48.34	- - -	51.66	- - -	100.00	- - -
132	do	10	NW 27	40N	79W	12,490	5,123	- -	- -	- -	4,429	Tr	5,975	222.85	- - -	- - -	- - -	124.93	- - -	97.92	56.06	- - -	43.94	- - -	100.00	- - -
133	do	14A	NW 27	40N	79W	17,236	7,000	36	- -	- -	6,600	- -	7,320	304.35	1.80	- - -	- - -	186.17	- - -	119.97	60.80	1.20	38.00	1.20	100.00	- - -
134	do	25A	SW 27	40N	79W	11,011	4,513	- -	- -	- -	3,953	418	4,325	196.33	- - -	- - -	- - -	111.51	13.93	70.89	56.80	- - -	43.20	- - -	100.00	- - -
135	do	M16	NE 30	40N	78W	11,500	4,630	- -	- -	- -	5,381	395	2,225	201.42	- - -	- - -	- - -	151.78	13.17	36.47	75.36	- - -	24.64	- - -	100.00	- - -
136	do	7	NW 29	40N	78W	12,043	4,825	25	13	89	5,075	Tr	4,100	209.89	1.25	1.07	1.85	143.16	- - -	67.20	68.34	- - -	30.58	1.08	98.71	1.29
137	do	17A	NW 29	40N	78W	12,831	5,206	- -	- -	- -	5,400	- -	4,525	226.48	- - -	- - -	- - -	152.32	- - -	74.16	67.26	- - -	32.74	- - -	100.00	- - -
138	do	18A	NW 29	40N	78W	11,585	4,700	- -	- -	- -	4,821	- -	4,075	204.47	- - -	- - -	- - -	137.68	- - -	66.79	67.34	- - -	32.66	- - -	100.00	- - -
139	do	19A	NW 29	40N	78W	11,888	4,807	- -	- -	- -	5,257	Tr	3,710	209.09	- - -	- - -	- - -	148.29	- - -	60.80	70.92	- - -	29.08	- - -	100.00	- - -
140	do	20	NW 29	40N	78W	12,359	5,055	- -	- -	- -	4,800	Tr	5,500	219.89	- - -	- - -	- - -	129.76	- - -	90.13	59.02	- - -	40.98	- - -	100.00	- - -
141	do	30Axe	NW 29	40N	78W	11,391	4,586	- -	- -	- -	5,333	120	2,750	199.50	- - -	- - -	- - -	150.43	4.00	45.07	75.40	- - -	24.60	- - -	100.00	- - -
142	do	3	NW 29	40N	78W	9,372	3,815	- -	- -	- -	3,762	480	2,675	165.96	- - -	- - -	- - -	106.12	16.00	43.84	63.94	- - -	36.06	- - -	100.00	- - -
143	do	36A	NW 34	40N	79W	8,664	3,535	- -	- -	- -	3,357	248	3,100	153.77	- - -	- - -	- - -	94.69	8.27	50.81	61.58	- - -	38.42	- - -	100.00	- - -
144	do	16A	NE 34	40N	79W	10,517	4,160	21	- -	413	4,786	- -	2,313	180.43	1.05	- - -	8.54	134.97	- - -	37.97	72.08	- - -	20.34	0.58	94.06	5.94
145	do	31A	SE 34	40N	79W	9,735	3,908	- -	- -	- -	4,381	185	2,626	171.11	- - -	- - -	- - -	121.57	6.16	41.38	74.22	- - -	27.78	- - -	100.00	- - -
146	do	1	NW 32	40N	78W	15,047	6,063	- -	- -	- -	6,762	358	1,725	261.73	- - -	- - -	- - -	190.75	11.93	61.05	72.32	- - -	27.68	- - -	100.00	- - -

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
	Salt Creek (Continued):										POWDER RIVER BASIN			(Continued from Page 1)											
147	Second Wall Creek Sand	29A	SW 32	40N	78W	10,274	4,104	16	Tr	Tr	5,050	--	2,245	178.45	0.80	---	---	142.45	---	36.80	79.40	---	20.16	0.44	100.00	---
148	do	30A	SW 32	40N	78W	11,638	4,680	---	---	---	5,534	121	2,650	203.56	---	---	---	156.10	4.03	43.43	76.68	---	23.32	---	100.00	---
149	do	31Ax	SW 32	40N	78W	10,989	4,427	---	---	---	5,099	101	2,770	192.59	---	---	---	143.83	3.36	45.40	74.50	---	25.50	---	100.00	---
150	do	30A	SE 32	40N	78W	10,780	4,341	---	---	---	5,029	72	2,720	188.84	---	---	---	141.86	2.40	44.58	75.12	---	24.88	---	100.00	---
151	do	31Ax	SE 32	40N	78W	10,965	4,408	Tr	---	---	5,250	24	2,610	191.67	---	---	---	148.09	0.80	42.78	77.36	---	22.64	---	100.00	---
152	do	30A	SE 32	40N	78W	10,648	4,264	14	Tr	7	5,100	24	2,520	185.41	0.70	---	0.15	143.86	0.80	41.30	77.38	---	22.24	0.38	99.89	0.11
153	do	1A	NW 3	39N	79W	8,747	3,571	---	---	---	3,357	Tr	3,700	155.33	---	---	---	94.69	---	60.64	60.96	---	39.04	---	100.00	---
154	do	2A	NW 3	39N	79W	9,721	3,959	---	---	---	3,857	Tr	3,875	172.31	---	---	---	108.80	---	63.51	63.14	---	36.86	---	100.00	---
155	do	4A	NW 3	39N	79W	10,621	4,360	---	---	---	3,714	246	4,675	189.65	---	---	---	104.76	8.27	76.62	71.54	---	28.46	---	100.00	---
156	do	24A	NW 3	39N	79W	10,146	4,098	---	---	---	4,548	185	2,675	178.28	---	---	---	128.28	6.16	43.84	71.96	---	28.04	---	100.00	---
157	do	25A	NW 3	39N	79W	10,393	4,216	---	---	---	4,381	Tr	3,650	183.39	---	---	---	123.57	---	59.82	67.38	---	32.62	---	100.00	---
158	do	18A	NE 3	39N	79W	9,055	3,633	---	---	---	4,189	120	1,775	158.02	---	---	---	124.93	4.00	29.09	79.06	---	20.94	---	100.00	---
159	do	34A	SE 3	39N	79W	9,519	3,834	---	---	---	4,489	248	2,050	166.80	---	---	---	124.93	8.27	33.60	74.90	---	25.10	---	100.00	---
160	do	CB2	SE 5	39N	78W	10,895	4,403	---	---	---	4,857	455	2,400	191.51	---	---	---	137.01	15.16	39.34	71.54	---	28.46	---	100.00	---
161	do	3	NE 10	39N	79W	8,847	3,421	24	10	83	4,350	Tr	1,950	148.74	1.20	0.82	1.73	117.07	---	31.96	79.20	---	20.20	0.60	98.74	1.26
162	do	36A	NE 10	39N	79W	10,031	4,055	---	---	---	4,452	Tr	3,100	176.39	---	---	---	125.48	---	50.81	71.20	---	28.80	---	100.00	---
163	do	12A	SE 11	39N	79W	4,306	1,735	Tr	---	---	2,000	Tr	1,160	75.43	---	---	---	56.42	---	19.01	74.80	---	29.20	---	100.00	---
164	do	21	SE 14	39N	79W	8,026	3,239	---	---	---	3,643	185	1,950	140.89	---	---	---	102.77	6.16	31.96	72.94	---	27.06	---	100.00	---
165	do	36A	SE 14	39N	79W	8,739	3,512	---	---	---	4,084	--	2,322	153.25	---	---	---	115.17	---	38.08	75.10	---	24.90	---	100.00	---
166	do	2	NW 16	39N	78W	5,846	2,380	Tr	---	Tr	2,350	--	2,270	103.49	---	---	---	66.29	---	37.20	64.00	---	36.00	---	100.00	---
167	do	18A	NW 19	39N	78W	6,454	2,861	---	---	---	2,095	192	2,650	124.58	---	---	---	74.75	6.40	43.43	60.00	---	40.00	---	100.00	---
168	do	GT3	SE 19	39N	78W	7,644	3,105	---	---	---	3,167	--	2,790	135.06	---	---	---	89.33	---	45.73	66.14	---	33.86	---	100.00	---
169	do	2	SW 20	39N	78W	13,702	5,574	---	---	---	5,548	60	5,125	242.48	---	---	---	156.49	2.00	85.99	64.54	---	35.46	---	100.00	---
170	do	1	SE 30	39N	78W	11,562	4,548	24	Tr	52	6,500	Tr	890	197.82	1.20	---	1.08	183.35	---	14.99	92.54	---	6.86	0.60	99.42	0.58
171	do	3A	NW 29	39N	78W	8,479	3,426	12	Tr	Tr	3,600	--	2,930	148.97	0.60	---	---	101.55	---	48.02	67.90	---	31.68	0.42	100.00	---
172	Third Wall Creek Sand	5	NE 20	39N	78W	16,369	6,506	---	---	60	8,500	Tr	2,650	284.44	---	---	1.25	239.76	---	43.43	84.70	---	15.30	---	99.48	0.52
173	do	33A	NE 20	39N	78W	16,433	6,537	Tr	---	Tr	8,900	--	2,025	284.24	---	---	---	251.05	---	33.19	88.32	---	11.68	---	100.00	---
174	do	32	SW 20	39N	78W	14,863	5,942	---	---	---	7,564	--	2,760	258.59	---	---	---	213.36	---	45.23	82.50	---	17.50	---	100.00	---
175	do	3	SW 20	39N	78W	17,268	6,891	---	---	---	9,000	Tr	2,800	299.76	---	---	---	253.87	---	45.89	84.70	---	15.30	---	100.00	---
176	do	7	SW 20	39N	78W	15,550	6,226	---	---	---	7,800	Tr	3,100	270.83	---	---	---	220.02	---	50.81	81.24	---	18.76	---	100.00	---
	Teapot Dome																									
177	First Wall Creek Sand	40E	SE 20	39N	78W	3,849	1,562	14	8	96	940	159	2,174	68.09	0.70	0.66	2.00	26.51	5.29	35.65	40.98	---	57.06	1.96	92.97	7.03
178	do	40F	SE 20	39N	78W	3,808	1,362	30	25	30	1,276	--	2,181	69.24	1.49	2.05	0.60	36.00	---	36.18	50.26	---	44.88	4.86	98.41	1.59
179	do	109	NW 29	39N	78W	3,225	1,348	---	---	---	771	113	2,020	58.62	---	---	---	21.75	3.76	33.11	37.10	---	62.90	---	100.00	---
180	do	103	NW 29	39N	78W	3,335	1,400	---	---	---	700	50	2,410	60.92	---	---	---	19.75	1.67	39.50	32.42	---	67.58	---	100.00	---
181	do	102	NW 10	38N	78W	2,845	1,195	Tr	---	---	600	30	2,075	51.93	---	---	---	16.92	0.99	34.02	32.50	---	67.50	---	100.00	---
182	Second Wall Creek Sand	401	SE 20	39N	78W	11,679	4,617	30	12	Tr	6,000	Tr	2,075	200.97	1.50	0.99	---	169.25	---	34.01	83.24	---	15.54	1.22	100.00	---
183	do	408	SE 20	39N	78W	9,501	3,840	Tr	---	Tr	4,250	Tr	2,870	166.92	---	---	---	119.68	---	47.04	71.80	---	28.20	---	100.00	---
184	do	409	SE 20	39N	78W	9,566	3,864	Tr	---	Tr	4,300	Tr	2,850	168.00	---	---	---	121.29	---	46.71	72.40	---	27.60	---	100.00	---
185	do	406	SE 20	39N	78W	9,734	3,910	6	10	Tr	4,340	73	2,835	170.16	0.30	0.82	---	122.39	2.40	46.49	71.46	---	27.88	0.66	100.00	---
186	do	202	SE 21	39N	78W	6,573	2,645	---	---	---	3,100	24	1,635	115.03	---	---	---	87.44	0.80	26.79	76.00	---	24.00	---	100.00	---
187	do	104	NE 29	39N	78W	9,525	3,813	Tr	---	Tr	4,800	Tr	1,855	165.80	---	---	---	135.40	---	30.40	82.00	---	18.00	---	100.00	---
188	do	108	NE 29	39N	78W	11,973	4,842	7	Tr	Tr	5,240	Tr	3,810	210.19	0.35	---	---	148.09	---	62.45	70.40	---	29.44	0.15	100.00	---
189	do	110	NE 29	39N	78W	12,968	5,247	Tr	---	Tr	5,700	Tr	4,110	228.15	---	---	---	160.79	---	67.36	70.60	---	29.40	---	100.00	---

TABLE III

FRONTIER FORMATION WATERS (*Concluded*)

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
											POWDER RIVER BASIN (Continued from Page 4)															
	Teapot Dome (Continued)																									
190	Second Wall Creek Sand	302	SW 27	39N	78W	12,497	5,005	12	tr	- -	6,100	- -	2,810	217.53	0.60	- - -	- - -	172.07	- - -	46.06	79.00	- - -	20.74	0.26	100.00	- - -
191	do	201	NW 11	38N	78W	12,387	4,864	44	6	58	6,320	- -	2,225	213.28	2.20	0.49	1.21	178.27	- - -	36.49	83.08	- - -	14.84	2.08	99.35	0.65
192	do	301	SW 11	38N	78W	12,481	4,932	42	12	tr	6,300	- -	2,430	214.45	2.10	0.99	- - -	177.71	- - -	39.83	81.68	- - -	16.96	1.36	100.00	- - -
193	Third Wall Creek Sand	409	SE 20	39N	78W	16,307	6,430	44	11	51	8,024	372	2,754	280.14	2.20	2.55	1.06	226.28	12.38	48.17	79.78	- - -	18.58	1.64	99.53	0.47
194	do	402	SE 33	39N	78W	15,874	6,000	8	14	3	8,153	331	2,776	285.06	0.45	1.15	0.06	230.00	11.10	45.50	80.32	- - -	19.12	0.56	99.98	0.02
195	Midway		SE 14	35N	79W	6,391	2,573	- - -	- - -	156	2,609	- -	2,140	111.93	- - -	- - -	3.25	73.60	- - -	35.08	68.66	- - -	31.34	- - -	95.78	4.22
196	Midway	11	NE 23	35N	79W	6,452	2,568	21	tr	113	2,850	tr	1,830	111.69	1.05	- - -	2.35	80.39	- - -	30.00	73.38	- - -	25.68	0.94	97.17	2.63
197	Midway	11	NE 23	35N	79W	7,062	2,811	21	- - -	80	3,250	tr	1,830	122.29	1.05	- - -	1.67	91.67	- - -	30.00	75.68	- - -	23.46	0.86	98.20	1.80
198	Cole Creek	1	SE 21	35N	77W	16,443	6,506	- - -	- - -	233	8,860	180	1,350	282.99	- - -	- - -	4.85	250.02	6.00	22.12	90.06	- - -	9.94	- - -	98.10	1.90
199	Cole Creek	1	SE 21	35N	77W	17,490	6,946	- - -	- - -	107	9,360	84	2,020	302.16	- - -	- - -	2.23	264.02	2.80	33.11	88.12	- - -	11.88	- - -	99.16	0.84
200	Big Muddy	4	2	33N	76W	5,967	2,537	- - -	- - -	- -	771	338	4,720	110.38	- - -	- - -	- - -	21.75	11.27	77.36	19.70	- - -	80.30	- - -	100.00	- - -
201	Big Muddy	9	3	33N	76W	6,801	2,867	- - -	- - -	- -	1,249	tr	5,460	124.71	- - -	- - -	- - -	35.23	- - -	89.48	28.24	- - -	71.76	- - -	100.00	- - -
202	Big Muddy	14	3	33N	76W	5,651	2,400	- - -	- - -	- -	771	306	4,421	104.41	- - -	- - -	- - -	21.75	10.20	72.46	20.84	- - -	79.16	- - -	100.00	- - -
203	Big Muddy	B-14	3	33N	76W	8,506	3,519	- - -	- - -	- -	2,565	185	4,550	153.08	- - -	- - -	- - -	72.35	6.16	74.57	47.26	- - -	52.74	- - -	100.00	- - -
204	Big Muddy	13	5	33N	76W	6,200	2,590	- - -	- - -	- -	1,500	468	3,340	112.66	- - -	- - -	- - -	42.31	15.60	54.75	37.56	- - -	62.44	- - -	100.00	- - -
205	Big Muddy	25	8	33N	76W	7,853	3,229	- - -	- - -	- -	2,667	133	3,710	180.46	- - -	- - -	- - -	75.23	4.43	60.80	53.56	- - -	46.44	- - -	100.00	- - -
206	Big Muddy	17	9	33N	76W	7,259	2,992	- - -	- - -	- -	2,595	109	3,260	130.26	- - -	- - -	- - -	73.20	3.63	53.43	56.20	- - -	43.80	- - -	100.00	- - -
207	Big Muddy	16	9	33N	76W	7,167	2,976	- - -	- - -	- -	1,976	tr	4,505	129.57	- - -	- - -	- - -	55.74	- - -	73.83	43.02	- - -	56.98	- - -	100.00	- - -
208	Big Muddy	18	9	33N	76W	7,528	3,122	- - -	- - -	- -	2,184	150	4,255	135.79	- - -	- - -	- - -	61.05	5.00	69.74	44.96	- - -	55.04	- - -	100.00	- - -
209	Big Muddy	19	9	33N	76W	8,508	3,530	- - -	- - -	- -	2,411	- -	5,220	153.56	- - -	- - -	- - -	68.01	- - -	85.55	44.28	- - -	55.72	- - -	100.00	- - -
210	Big Muddy	21	9	33N	76W	5,712	2,353	- - -	- - -	- -	1,858	205	2,630	102.36	- - -	- - -	- - -	52.42	6.84	43.10	51.22	- - -	48.78	- - -	100.00	- - -
211	Big Muddy	26	9	33N	76W	5,885	2,479	- - -	- - -	- -	1,107	192	4,285	107.84	- - -	- - -	- - -	31.21	6.40	70.23	28.94	- - -	71.06	- - -	100.00	- - -
212	Irvine	1	NE 5	31N	70W	2,318	1,371	22	- - -	26	130	70	1,420	28.27	1.10	- - -	0.54	3.67	2.33	23.27	9.64	- - -	85.20	5.16	87.17	12.83

*Analyses courtesy Midwest Refining Company.

bine with the carbonate to form insoluble carbonates of calcium and magnesium and precipitate out.

SUMMARY

The Shannon sandstone waters of the Powder River Basin are of a sodium chloride-bicarbonate type in those fields in which the sandstone is deeply buried, and fed only by a fresh-water source. Where the sandstone crops out on or near a field, the sulphate radicle predominates, with or without the alkaline earths, according to whether zeolite or base-exchange action has taken place.

FRONTIER FORMATION WATERS

The Frontier formation, consisting of the Wall Creek sandstone members and associated shale in most of Wyoming and of the Torchlight and Peay sandstone members and associated shale in the Big Horn Basin, is of Upper Cretaceous age and the next important oil and water-bearing zone below the Shannon sandstone. Where it produces oil the formation ranges from 370 to 1,200 feet in thickness and contains two to nine beds of sandstone.

Where the Frontier is faulted and its constituent beds lenticular and not identifiable, the water samples therefrom are labeled "Frontier." Where the several Wall Creek sands can be separated, water samples therefrom are designated "First Wall Creek," "Second Wall Creek," *et cetera.*

Frontier waters are characterized by primary salinity and primary alkalinity, the salinity being largely caused by the chloride radicle. Except in Cole Creek and Midway fields, sulphate is absent in normal Frontier waters. Calcium and magnesium occur in small amounts in some waters and are absent in others. In no case is there sufficient calcium or magnesium to give secondary salinity to the water. The almost total absence of hardness is attributed to base-exchange action. Bentonite beds occur in the shale members and as lentils in the sandstones.

The concentration of Frontier waters varies widely, ranging from 50,000 parts per million total solids in Baxter Basin to 1,200 in Eight Mile Lake. This variation in concentration depends largely on the lenticularity of the formation, and its location with respect to its outcrop.

Frontier waters are essentially solutions of sodium chloride and sodium bicarbonate in varying proportions.

BIG HORN BASIN

Elk Basin oil field.—In the main part of the Elk Basin field the

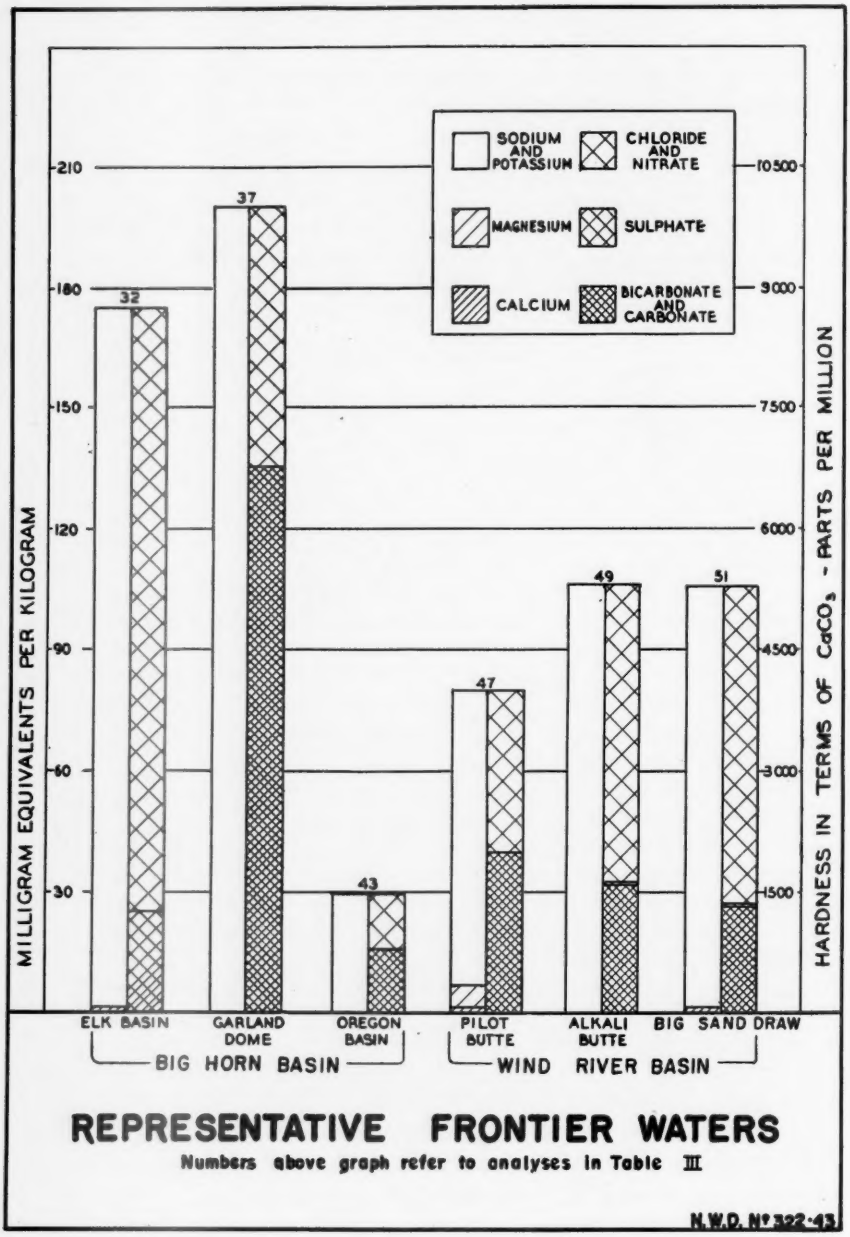

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
210
180
150
120
90
60
30
10500
9000
7500
6000
4500
3000
1500
32
37
43
47
49
51
ELK BASIN
GARLAND DOME
OREGON BASIN
PILOT BUTTE
ALKALI BUTTE
BIG SAND DRAW
BIG HORN BASIN
WIND RIVER BASIN
REPRESENTATIVE FRONTIER WATERS
Numbers above graph refer to analyses in Table III
N.W.D. Nº 322-43

FIG. 5

Frontier consists of two sandstones separated by shale, but in the south extension there are alternating layers of highly faulted sandstone and shale. The formation produces water with the oil. The depth to the top of the Frontier in the main part of the field is less than 1,000 feet and averages about 1,850 feet in the southern part.

Analyses 31–36, in Table III, show that the Frontier water is of the primary saline type, with some primary alkalinity and a very small amount of secondary alkalinity. Sulphate is absent. The chemical system averages about 85 per cent sodium chloride and 14 per cent sodium bicarbonate, the remaining 1 per cent being calcium bicarbonate.

The only other water in the Elk Basin field that enters seriously into production problems is that from the Eagle sandstone, which contains sulphate and a chloride radicle of 100 parts per million or less, both of which differentiate it from Frontier water.

Garland dome.—The one sample of Frontier water from the Garland field was obtained off structure and on the downthrown side of a normal fault at an exceptional depth of 3,200 feet, the depth to the top of the Peay sandstone on the "high" of the structure being about 600 feet. The well made more than 100 barrels of oil a day for a few days but rapidly went to water.

The aforementioned sample has about the same concentration as Frontier water at Elk Basin, but the chemical system consists of 33 per cent sodium chloride and 67 per cent sodium bicarbonate; in other words, primary alkalinity dominates, which is the reverse of conditions at Elk Basin. Sulphate and the alkaline earths are absent.

The presence of appreciable quantities of sulphate in the deeper Madison water in the Garland field distinguishes it from the Frontier water.

Only gas has been found in the Frontier formation in the contiguous Byron field.

Oregon Basin.—The Frontier formation in the Oregon Basin oil field averages about 575 feet in thickness and crops out on the top of both the north and south domes. It carries non-commercial amounts of oil and gas downdip.

Although the Frontier lies close to the surface, its water is remarkably consistent in character. Analyses 38–40, Table III, were taken from on top of the north dome at a depth of about 1,000 feet. Analyses 41–44 are from on top the south dome at a depth of about 420 feet. The chloride content of the water is greater in the southern, or shallower, part of the field.

This water is one of the most dilute Frontier waters in the state,

averaging about 1,500 parts per million total solids, and is a solution of 85 per cent sodium bicarbonate and 15 per cent sodium chloride. Sulphate is present only as a contamination.

This water can be used for oil-field operations, as it is soft and non-corrosive. However, when used in boilers sulphate should be added to prevent hydrogen embrittlement.

The deeper Chugwater and Embar waters are distinguished from the Frontier water by their large quantity of sulphate and higher concentration.

Skelton dome.—The top of the Frontier formation was found at a depth of 2,245 feet in the one well drilled on the unproductive Skelton dome. The Frontier water is very similar to that at Oregon Basin, both in concentration and in the proportions of chloride and bicarbonate. This water can be used in boilers satisfactorily if sulphate is added to prevent hydrogen embrittlement.

Neiber dome.—The top of the Frontier formation at a depth of 7,260 feet in a deep well on the unproductive Neiber dome yielded 27 barrels of water per hour. The water is similar to Frontier water in other fields on the north, the sulphate present probably being contamination from drilling water.

A sandstone in the Fort Union formation at a depth of 300 feet on the dome yields water that is easily distinguished from the Frontier water by its high sulphate content.

WIND RIVER BASIN

Pilot Butte field.—In the Pilot Butte field the unproductive Frontier formation consists of 2–7 sandstones with many shale partings. Analysis 47, Table III, came from a sand at a depth of 1,910 feet.

The Frontier water is more concentrated than equivalent waters in the Big Horn Basin. In addition, it has a greater proportion of sodium chloride in relation to sodium bicarbonate, resembling Frontier waters in the gas area near Riverton and representing a transition between the alkaline water in the Frontier of the Big Horn Basin and the saline water found in the Big Sand Draw and Alkali Butte gas fields.

Water from a sand in the Steele shale, 800 feet above the Frontier formation in the Pilot Butte field, has a concentration ranging from 7,000 to 15,000 parts per million but is distinguished from Frontier water by its greater chloride-bicarbonate ratio.

Alkali Butte field.—The Frontier water in the sharply folded Alkali Butte field is somewhat similar to equivalent water at Pilot Butte. The Frontier consists of two to seven sandstones, interfingering

with shale, and lentils of bentonite. The formation is about 765 feet thick and lies about 2,500 feet deep.

In the Alkali Butte field the Frontier water, though still containing sodium chloride and sodium bicarbonate, has changed from an alkaline to a saline type; that is, sodium chloride exceeds sodium bicarbonate. About 70 per cent of the chemical system is sodium chloride, the remaining 30 per cent being sodium bicarbonate.

The concentration of the Frontier water at Alkali Butte varies considerably, as would be expected in a sharply folded structure. However, by ignoring the concentration and using the percentage of its constituents, this water can be easily correlated.

Other water sands occur in the Alkali Butte field in the Mesaverde formation and Steele shale, above the Frontier, and in the Muddy sand, below the Frontier. The waters from both the Mesaverde and Muddy sandstones are easily distinguished from Frontier water by their sulphate content and by the great difference in concentration. The water from the Steele shale resembles Frontier water on cursory examination, but can be distinguished by means of the high chloride-bicarbonate ratio.

Big Sand Draw gas field.—The gas-bearing Frontier formation in the Big Sand Draw field is lithologically like that at Alkali Butte and Pilot Butte. It is about 700 feet thick and lies about 2,400 feet below the surface.

The well from which analyses 50 and 51, Table III, were taken was drilled on the flank of the anticline. The alkaline earths and sulphate present in the water are contamination from drilling water. The water has 75 per cent primary salinity and 25 per cent primary alkalinity, an increase of about 5 per cent in salinity over that at Alkali Butte.

SWEETWATER BASIN

Baxter Basin gas fields.—North, Middle, and South Baxter Basin gas fields lie along the axis of the Rock Springs uplift. In these fields the Frontier formation is composed of two to five lenticular sandstones, interbedded sandy shale, and bentonite.

In North Baxter Basin the top of the Frontier occurs at an average depth of 2,400 feet and contains only water. In Middle Baxter Basin an important water-bearing Frontier sandstone is found at a depth of 1,800 feet. At South Baxter Basin the Frontier produces sweet gas in commercial quantity at depths ranging from 1,800 to 2,700 feet.

Although the Frontier sands at Baxter Basin are lenticular and faulting is common, and the water analyses are irregular, a consistent

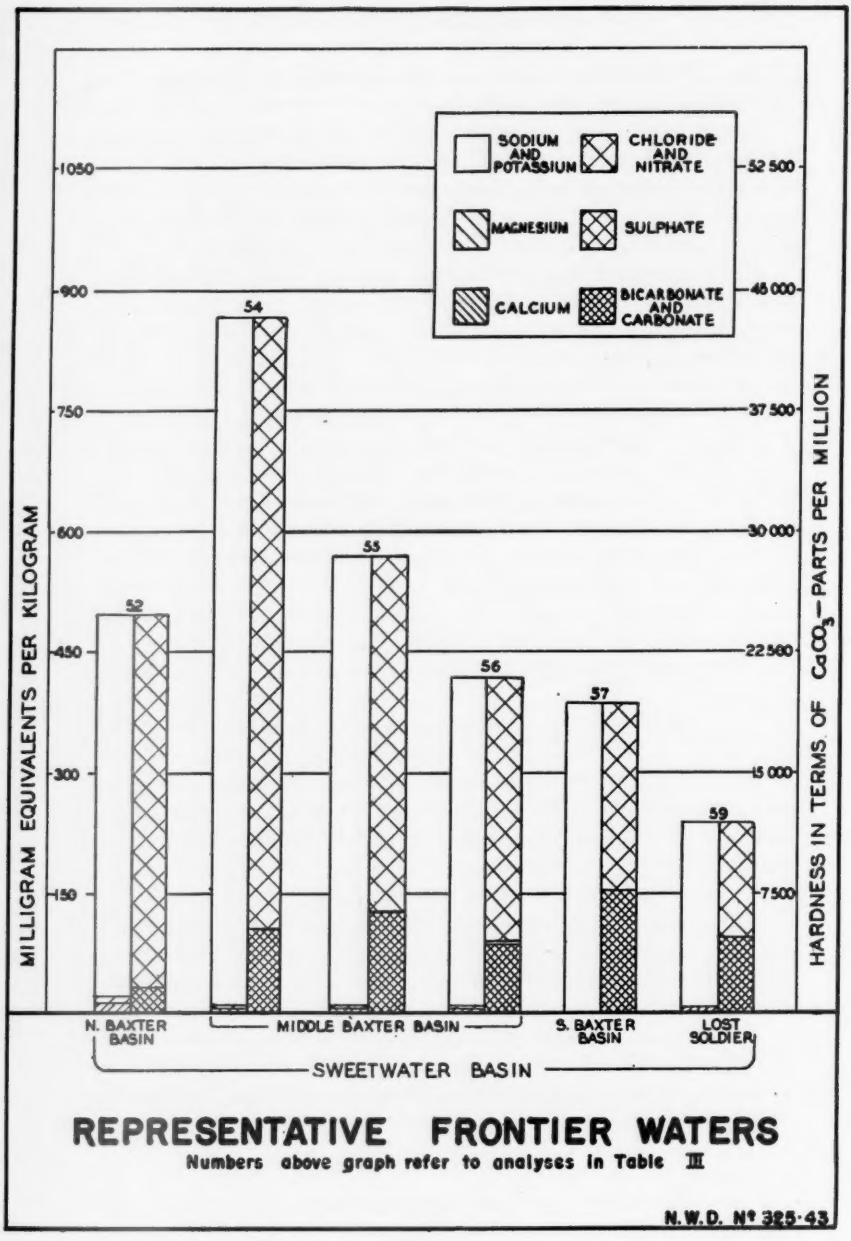

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ — PARTS PER MILLION
1050
900
750
600
450
300
150
52 500
45 000
37 500
30 000
22 500
15 000
7 500
52
54
55
56
57
59
N. BAXTER BASIN
MIDDLE BAXTER BASIN
S. BAXTER BASIN
LOST SOLDIER
SWEETWATER BASIN
REPRESENTATIVE FRONTIER WATERS
Numbers above graph refer to analyses in Table III
N.W.D. Nº 325-43

FIG. 6

decrease in salinity and increase in alkalinity from north to south is noted, the alkaline earths also displaying the same regular decrease from north to south.

The Frontier water at Baxter Basin is a highly concentrated solution of sodium chloride and bicarbonate, similar to other Frontier waters described, but the concentration is the highest of any Frontier water analyzed. Analyses 53 and 54 show more than 50,000 parts per million total solids. These samples were taken from a well that was making gas, and the evaporative effect of the expanding gas may have been an important factor in this exceptionally high concentration. It is also possible that the high and variable concentration of the Frontier water is caused by the wedge nature of the sandstones.

The source water in the Frontier at Baxter Basin is largely connate sea water trapped in sand lenses and subsequently sealed therein by silica and carbonates. As stagnant conditions are present in the sand, very little dilution with fresh water has occurred. Faults and fractures throughout the area have permitted the mingling of formation waters to some extent, and exact correlations are difficult to make by means of water analyses.

Lost Soldier field.—In the Lost Soldier field five of the nine sandstones in the Frontier formation yield oil. The sands are thin-bedded and one is about 60 feet thick. All sands produce edge water, but the most consistent water sand lies about 680 feet below the surface. The formation is about 900 feet thick and is reached at depths ranging from 200 to 900 feet. The intake of its water is at its outcrops in the Green Mountains and in the Ferris Mountains just north of the field.

The Frontier water in the Lost Soldier field has a dissolved salt content of 65 per cent sodium chloride and 35 per cent sodium bicarbonate. Traces of sulphate and the alkaline earths are present only as contamination by drilling water. The water is similar in character and concentration to that in the Second Wall Creek sand in the Salt Creek field, and its comparatively high concentration suggests little circulation in the sand.

The waters from the Dakota (?) sandstone and the Sundance formation in the Lost Soldier field are distinguished by their higher alkalinity from the typical saline and higher concentrated water of the Frontier.

Eight Mile Lake anticline.—Water is the only fluid in the sandstones and shaly sand of the Frontier formation along the Eight Mile Lake anticline, the water having entered the Frontier at its outcrop along the flanks of the Sierra Madre Mountains.

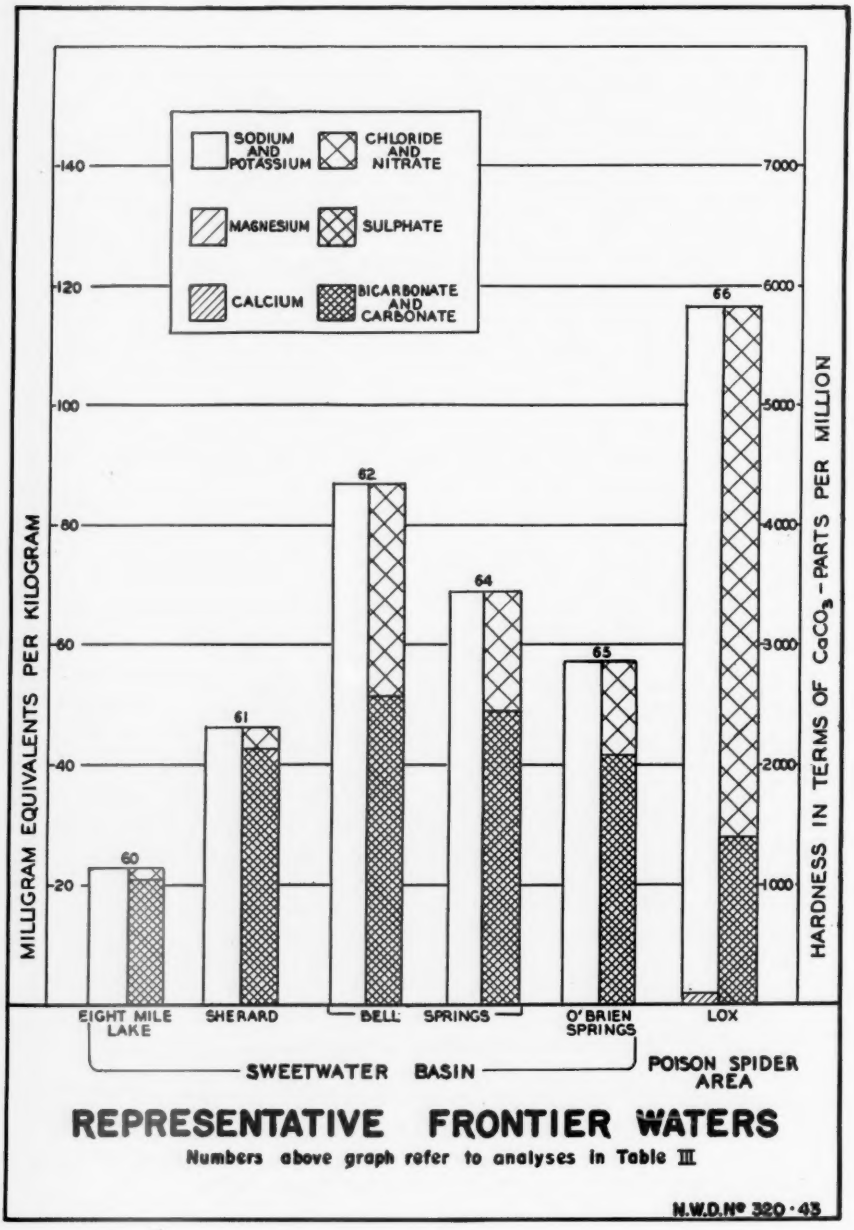

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
140
120
100
80
60
40
20
7000
6000
5000
4000
3000
2000
1000
60
61
62
64
65
66
EIGHT MILE LAKE
SHERARD
BELL
SPRINGS
O'BRIEN SPRINGS
LOX
SWEETWATER BASIN
POISON SPIDER AREA
REPRESENTATIVE FRONTIER WATERS
Numbers above graph refer to analyses in Table III
N.W.D.Nº 320-43

FIG. 7

The top of the water sand in the well from which analysis 60, Table III, was taken lies at a depth of 1,128 feet and is 2 feet thick. This water is the most dilute Frontier water analyzed, having a concentration of 1,200 parts per million and a dissolved salt content of 94 per cent sodium bicarbonate and 6 per cent sodium chloride. The water is usable in oil-field operations and can be used also for domestc purposes, although not recommended.

Sherard, Bell Springs, and O'Brien Springs areas.—In the Sherard, Bell Springs, and O'Brien Springs areas the Frontier sandstones and shales are about 800 feet thick. At Sherard the top of the Frontier lies 2,600 feet below the surface. Its water is of the alkaline type and is similar in chemical character to the Frontier water at Eight Mile Lake, though more concentrated. The well from which analysis 61, Table III, was obtained flows 75 barrels of water per hour, which is used by the Iowa Soda Products Company in boilers and to dissolve mirabilite.

On the Bell Springs anticline the Frontier ranges in depth from 865 to 2,200 feet. Analysis 62 is from a well far down on the flank of the structure, 63 from one on the crest, and 64 from one on the south flank. This water is of the primary alkaline type, and the concentration and salinity both increase down the dip. Although analysis 63 is from the top of the structure, it is the lowest in concentration and chloride content, whereas analysis 62, low on the limb of the structure, contains more than twice as much chloride. The chloride-bicarbonate ratio ranges from 0.4 near the crest to 0.7 on the flanks. The water can be used in oil-field operations, but the addition of sufficient sulphate to prevent hydrogen embrittlement is desirable.

In the O'Brien Springs area the top of the Frontier formation lies about 2,600 feet below the surface. As shown by analysis 65, the water is similar to that at Bell Springs.

POISON SPIDER AREA

Lox structure.—The one well drilled on the Lox structure found the First Wall Creek sand at 1,774–1,940 feet and the Second Wall Creek sand at 2,175–2,235 feet. At a total depth of 2,458 feet the hole was still in the Frontier formation. Three million cubic feet of gas, with water, was found in a 20-foot sand at 2,068 feet, the water eventually drowning out the gas.

Analysis 66, which probably came from the Second Wall Creek sand, is essentially a solution of sodium chloride and sodium bicarbonate, 75 per cent of the chemical system being sodium chloride.

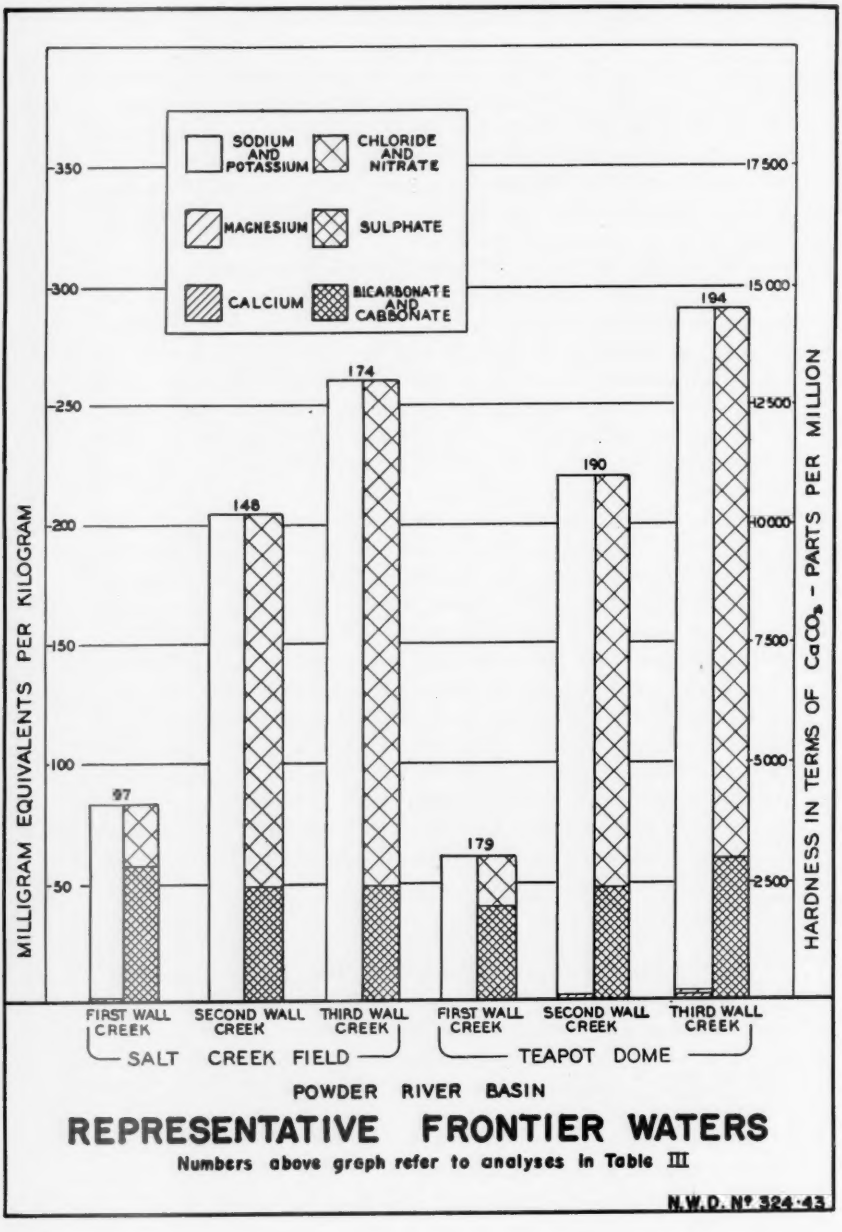

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
350
300
250
200
150
100
50
17500
15000
12500
10000
7500
5000
2500
97
148
174
179
190
194
FIRST WALL CREEK
SECOND WALL CREEK
THIRD WALL CREEK
FIRST WALL CREEK
SECOND WALL CREEK
THIRD WALL CREEK
SALT CREEK FIELD
TEAPOT DOME
POWDER RIVER BASIN
REPRESENTATIVE FRONTIER WATERS
Numbers above graph refer to analyses in Table III
N.W.D. Nº 324-43

FIG. 8

POWDER RIVER BASIN

Salt Creek area.—The top of the Frontier formation in the Salt Creek area lies at an average depth of 1,000 feet and consists of the First Wall Creek sand, 125 feet thick; 160 feet of shale, shaly sand and bentonite; the Second Wall Creek sand, 60 feet thick; 150 feet of gray shale and sandy shale; the Third Wall Creek sand, 15 feet thick; and 250 feet of dark shale. The Third Wall Creek sand is lenticular, having its principal development in the southeast part of the Salt Creek field. All the Wall Creek sands produce oil and water, the second being the more important producer of oil.

The Frontier waters in the Salt Creek area are solutions of sodium chloride and sodium bicarbonate, differing only in concentration and chloride-bicarbonate ratio. Although the waters are distinguishable, variations within a single sand necessitate correlations with known waters from near-by wells. The calcium, magnesium, and sulphate reported in many analyses are probably contamination by surface and drilling water. Many of the samples in Table III were taken from drilling wells, and later samples from flow tanks and lead lines show no sulphate or alkaline earths. The carbonate present in most of the analyses is acquired by exposure, as the water *in situ* contains no normal carbonate.

The concentration and chloride-bicarbonate ratio is not uniform in the First Wall Creek sand waters. The concentration is about 3,000 parts per million around the edge of the structure and increases to 10,000 parts per million updip in the productive area. A concentration of 3,000 parts per million is found in Teapot dome. The chloride content averages about 600 parts per million in the northern end of the Salt Creek field and drops to 300 in the southern end. In the productive area—Secs. 23, 24, 25, 27, 34, 35, and 36, T. 40 N., R. 79 W.—the chloride is as high as 5,000 parts per million, and the water resembles the Second Wall Creek sand water. These exceptional First Wall Creek sand waters are represented in Table III by analyses 77–79, 82–84, and 88–90. In this area correlations should be made by comparison with known waters from neighboring wells, rather than by relying on the general features of the waters.

The First Wall Creek sand water, where the chloride content is low, has been successfully used in oil-field operations in the Salt Creek field. Frequent blowing down is necessary when used as a boiler water, as it has a tendency to foam and prime.

The Second Wall Creek sand water has a decided increase in chloride and concentration over the First sand water and the salinity is in excess of the alkalinity, except in a few instances. The concen-

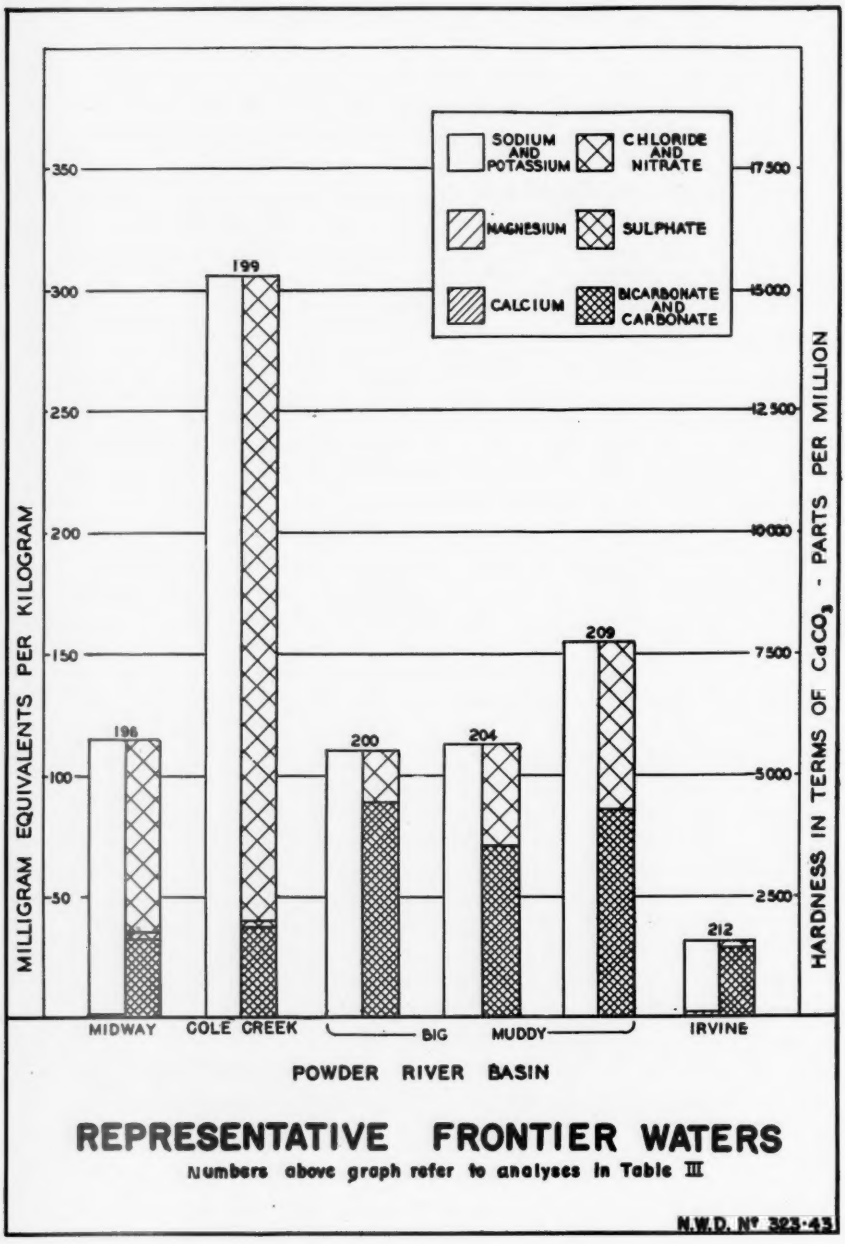

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
350
300
250
200
150
100
50
17500
15000
12500
10000
7500
5000
2500
196
199
200
204
209
212
MIDWAY
COLE CREEK
BIG
MUDDY
IRVINE
POWDER RIVER BASIN
REPRESENTATIVE FRONTIER WATERS
Numbers above graph refer to analyses in Table III
N.W.D. Nº 323-43

FIG. 9

tration is about 11,000 parts per million, and the concentration increases from south to north over the structure. The chloride content of this water averages 4,000 parts per million and varies from 3,000 in the south end of the field to 5,000 in the north.

The Third Wall Creek sand water has been sampled only in the southern part of the Salt Creek field; that is, in Section 20. This water has an average concentration of 16,000 parts per million, with 8,000 parts per million of chloride present. It differs from the Second Wall Creek sand water only in these two respects, but does not enter seriously into production problems.

The Frontier waters of Teapot dome are similar to those of the Salt Creek field.

Most of the sands below the Frontier contain water in appreciable quantities, which can be distinguished from Frontier waters by their concentration and the presence of sulphate, calcium, and magnesium.

The source waters for the Frontier sands of the Salt Creek area are the primary alkaline waters of the Big Horn Mountains. The concentration of the Wall Creek waters suggests a comparatively active water movement in the First Wall Creek sand, a less active, almost stagnant, condition in the second sand, and a totally stagnant condition in the third sand.

Midway structure.—Three wells have been drilled on the Midway structure. In the discovery well the Frontier formation was found at 4,715–5,790 feet. The First Wall Creek sand had a thickness of 60 feet and contained some water, but no samples were obtained. The Second Wall Creek sand, in which commercial oil production was found, was logged at 5,162–5,232 feet. The Third Wall Creek sand was missing.

Water samples were taken only of the Second Wall Creek sand water. This water, which is more dilute than that of the Salt Creek area, is a saline water bearing a close chemical resemblance to the Second Wall Creek sand water of the Salt Creek area. The sulphate may be a constituent of the water in its natural state, or may be drilling-water contamination, as all samples were taken from drilling wells.

The Lakota water has been sampled and can be distinguished from the Frontier by its lower concentration, the presence of definite quantities of sulphate, and its alkaline character.

Source waters for the Frontier sand in the Midway field are probably from the Laramie Mountains, and the concentration of the water suggests a water movement in the sand that is but slightly less active than that of the First Wall Creek sand in the Salt Creek area.

Cole Creek structure.—The top of the Frontier was found at 6,680 feet in one well drilled on this structure. A tight, lenticular sand was found down to 6,740 feet, and the bottom of the Frontier was logged at 7,810 feet. No second or third sands were present. Oil showings and 6 barrels of water per hour were obtained on test, but the sand was too tight for commercial oil production.

The two samples obtained while the sand was being tested show a highly saline character comparable with the Third Wall Creek sand water of the Salt Creek field. Its concentration of 17,000 parts per million and the tightness of the sand suggest a stagnant water condition, probably due to local impermeability of the sand.

The sulphate present in the water may be a constituent of the formation water or may be drilling-water contamination. Oil production from this Cole Creek well is obtained from the Lakota sand, which also contains water. The two waters can be distinguished because the Frontier water is more concentrated and the Lakota water contains considerable sulphate.

Big Muddy oil field.—The important oil-producing sand at Big Muddy is in the First Wall Creek sand in the Frontier formation. The entire Frontier formation is about 900 feet thick, and the main sand has an average thickness of 140 feet and lies about 3,000 feet below the surface.

The Frontier water in this field, although not uniform, is of the primary alkaline type. The chloride-bicarbonate ratio varies considerably, from a low of 0.3 in the northern section of the field, to a high of unity in the southern part. Its average concentration is 7,000 parts per million total solids, indicating a somewhat more active water movement in this sand than in the Shannon sandstone above.

Irvine area.—The Irvine area lies at the extreme south edge of the Powder River Basin, near the north end of the Hartville uplift and northeast of the Laramie Mountains, from which it receives at least part of its source waters. In this area the Frontier sandstones have largely feathered out. Eighteen feet of sandstone was found at 1,560–1,578 feet in one well drilled to the Triassic "Red Beds" and then plugged.

The water is comparatively dilute and is typically alkaline. The sulphate and calcium present are undoubtedly due to surface or drilling-water contamination, and in its natural state the water would contain 90 per cent sodium bicarbonate and 10 per cent sodium chloride.

SUMMARY

Frontier waters are essentially solutions of sodium chloride and sodium bicarbonate in varying proportions. At Elk Basin, one per

cent of calcium bicarbonate is present in the system, and at Midway and Cole Creek a very small percentage of the salinity may be due to sodium sulphate.

The salinity and alkalinity vary in accordance with the concentration of the water which, in turn, is controlled by the water movement in the sand. Where water movement is slow or flanking in character, the concentration increases and the water is saline; where the water movement is comparatively rapid, the concentration is decreased and the water is alkaline in character.

Excluding Elk Basin, with a salinity of 85 per cent, Big Horn Basin waters from the Frontier are alkaline. At Oregon Basin and Skelton dome the alkalinity is 85 per cent, and decreases in the fields toward the north and south.

Pilot Butte, in the Wind River Basin, is representative of the change from the alkaline waters of Big Horn Basin to the saline waters of the Big Sand Draw and Alkali Butte fields. At Pilot Butte the salinity and alkalinity are about equal, but the salinity increases south and east to 75 per cent at Big Sand Draw.

In the Sweetwater Basin saline water is found at Lost Soldier and Baxter Basin, but in the fields south of Separation Flats alkalinity dominates, increasing from north to south until it reaches a maximum of 94 per cent in the Eight Mile Lake structure on the south edge of the basin.

Salinity dominates the Frontier water of the northern and central Powder River Basin; south and east, salinity decreases and alkalinity increases to 90 per cent at Irvine on the south edge of the Powder River Basin. East of Irvine the Frontier sandstone is replaced by impermeable shaly sand.

"DAKOTA GROUP" WATERS

The "Dakota group" is the next important oil and water-bearing unit below the Frontier. The term "Dakota group," as used herein, follows the usage of many authors to include in ascending order the Cloverly formation, the Dakota (?) sandstone and the Muddy sand of central Wyoming, the Greybull sandstone in the Big Horn Basin, and their probable equivalents in eastern Wyoming—the Lakota sandstone and Fuson shale, Fall River sandstone, and the Newcastle sandstone member of the Graneros shale. All are of Cretaceous age.

Waters of the "Dakota group" vary in concentration from 30,000 parts per million in Baxter Basin to less than 500 in the Poison Spider area. Ordinarily the water in the Muddy sand contains the largest quantity of dissolved solids, the Dakota (?) sandstone the next, and the Lakota the least. The waters range from a primary saline type to

TABLE IV

Dakota Group Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
														RED RIVER BASIN											
213	Francie (Greybull)					1,114	419	Tr	--	329	43	99	533	18.20	---	---	6.90	1.20	1.30	8.80	44.60	---	55.40	---	14.80	85.20
214	Francie (Cloverly)	1	NW 25	52N	98W	737	171	34	12	300	30	--	185	7.44	1.70	0.99	6.25	0.85	---	3.03	70.00	---	4.00	26.00	11.40	88.60
215	Torchlight (Greybull)	4	NE 25	51N	93W	2,284	851	--	--	823	88	42	975	37.00	---	---	17.14	2.48	1.40	15.98	53.02	---	46.98	---	12.64	87.36
216	Hamilton Dome (Cloverly)	4	NW 14	44N	98W	2,665	1,013	--	--	826	133	--	1,410	44.06	---	---	17.20	3.75	---	23.11	47.56	---	52.44	---	17.91	82.09
217	Hamilton Dome (Cloverly)	10	NW 14	44N	98W	2,706	1,041	--	--	758	147	67	1,410	45.27	---	---	15.78	4.15	2.23	23.11	44.02	---	55.98	---	20.81	79.19
218	Shelton Dome (Greybull)	1	23	45N	100W	1,124	415	20	Tr	324	35	--	690	18.05	1.00	---	6.75	0.99	---	11.31	40.60	---	59.20	5.20	12.80	87.20
219	Shelton Dome (Greybull)	1	23	45N	100W	554	183	43	Tr	58	40	--	475	7.98	2.15	---	1.21	1.13	---	7.79	23.20	---	56.60	20.20	48.30	51.70
220	Shelton Dome (Greybull)	1	23	45N	100W	1,179	430	24	Tr	350	35	--	710	18.71	1.20	---	7.29	-0.99	---	11.63	41.60	---	52.20	6.20	12.00	88.00
221	Lake Creek (Muddy)	A1	NW 26	43N	91W	989	395	--	--	292	13	84	600	17.21	---	---	4.21	0.37	2.80	9.83	26.60	---	73.40	---	6.04	93.96
														RED RIVER BASIN											
222	Alkali Butte (Muddy)	2				11,719	4,645	--	--	705	4,682	--	3,065	202.06	---	---	14.67	137.15	---	50.24	75.14	---	24.86	---	90.34	9.66
														SWEETWATER BASIN											
223	N. Baxter Basin (Dak.?)	1	SW 32	21N	103W	16,986	6,835	60	57	101	10,000	--	475	284.28	2.99	4.69	2.10	282.08	---	7.78	97.34	---	0.04	2.62	99.28	0.72
224	N. Baxter Basin (Dak.?)	1	SW 32	21N	103W	17,401	6,946	164	81	306	9,800	--	1,025	284.77	8.18	6.66	6.37	276.44	---	16.80	94.40	---	0.66	4.94	97.76	2.24
225	N. Baxter Basin (Dak.?)	1	SW 11	20N	104W	15,395	5,975	110	Tr	116	8,476	--	1,460	259.93	5.49	---	2.41	239.08	---	23.93	90.98	---	6.96	2.06	99.00	1.00
226	N. Baxter Basin (Dak.?)	1	NE 13	19N	104W	32,905	12,500	232	164	--	19,200	--	1,645	543.49	11.58	13.48	---	541.59	---	26.96	95.26	---	0.32	4.42	100.00	---
227	M. Baxter Basin (Dak.?)	1	SE 18	18N	103W	15,818	6,461	--	--	36	5,928	--	6,900	281.06	---	---	0.75	167.22	---	113.09	59.76	---	40.24	---	99.56	0.44
228	M. Baxter Basin (Dak.?)	1	SE 18	18N	103W	15,799	6,456	--	--	23	5,928	--	6,900	280.79	---	---	0.48	167.22	---	113.09	59.72	---	40.28	---	99.72	0.28
229	S. Baxter Basin (Dak.?)	11	NE 2	17N	104W	8,180	3,328	--	--	44	3,202	276	2,705	144.77	---	---	0.92	90.32	9.20	44.33	63.02	---	36.98	---	98.99	1.01
230	S. Baxter Basin (Dak.?)	11	NE 2	17N	104W	10,309	4,083	56	33	--	4,032	--	4,260	178.04	2.80	2.71	---	113.73	---	69.82	61.96	---	35.04	3.00	100.00	---
231	Lost Soldier (Muddy)	42	3	26N	90W	9,506	3,909	--	--	--	3,202	Tr	4,870	170.14	---	---	---	90.32	---	79.82	53.08	---	46.92	---	100.00	---
232	Lost Soldier (Upper Cl.)	72	SE 3	26N	90W	4,277	1,761	--	--	--	1,119	Tr	2,800	77.46	---	---	---	31.57	---	45.89	40.76	---	59.24	---	100.00	---
233	Lost Soldier (Basal Cl.)	50	3	26N	90W	4,933	2,015	24	Tr	54	1,350	Tr	3,160	87.64	1.20	---	1.12	38.08	---	51.63	41.78	---	56.86	1.36	96.98	3.02
234	Lost Soldier (Basal Cl.)	67A	NW 11	26N	90W	5,436	2,219	32	20	266	1,300	--	3,510	96.47	1.60	1.64	5.52	36.67	---	57.53	42.20	---	54.60	3.20	87.20	12.80
235	Lost Soldier (Basal Cl.)	3	SE 3	26N	90W	6,073	2,580	Tr	--	93	1,150	--	4,750	112.23	---	---	1.94	32.44	---	77.85	30.60	---	69.40	---	94.12	5.88
236	Lost Soldier (Basal Cl.)	4	SE 3	26N	90W	4,805	2,019	16	Tr	120	700	--	4,050	87.82	0.79	---	2.50	19.75	---	66.38	25.10	---	74.00	0.90	88.84	11.16
237	Eight Mile Lake (Muddy)	1	35	20N	88W	24,051	9,000	314	95	--	14,256	--	785	391.51	15.67	7.81	---	402.13	---	12.86	94.34	2.56	---	3.10	100.00	---
238	Eight Mile Lake(Upper Cl.)	1	2	19N	88W	7,299	2,905	25	--	--	3,510	50	1,645	126.38	1.25	---	---	99.00	1.67	26.96	78.88	---	20.14	0.98	100.00	---
239	Eight Mile Lake(Upper Cl.)	3	NW 2	19N	88W	4,672	1,943	26	3	50	2,000	--	1,745	84.51	1.30	0.25	1.04	56.42	---	28.60	66.84	---	31.32	1.76	98.08	1.92
														LARAMIE BASIN											
240	N.Rock River(Upper Cl.)	3	33	26N	76W	872	356	--	--	111	73	138	396	15.45	---	---	2.31	2.06	4.60	6.48	28.28	---	71.72	---	47.13	52.87
241	N.Rock River(Lower Cl.)	3	33	26N	76W	665	223	--	--	309	62	24	85	9.92	---	---	6.44	1.29	0.80	1.39	77.92	---	22.08	---	16.68	83.32
242	Rock Creek (Cloverly)	2	NE 2	19N	78W	19,674	7,574	120	26	--	11,880	--	150	329.45	5.99	2.14	---	335.12	---	2.46	97.60	1.68	---	0.72	100.00	---
243	Rock Creek (Cloverly)	4	NE 3	19N	78W	15,618	6,174	--	--	--	9,018	84	695	268.57	---	---	---	254.38	2.80	11.39	94.72	---	5.28	---	100.00	---

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
												LARAMIE BASIN (Continued from Page 1)														
244	Rock Creek (Cloverly)	5	NE 3	19N	78W	5,368	2,156	- -	- -	- -	2,592	296	660	93.80	- - -	- - -	- - -	73.12	9.87	10.81	77.96	- - -	22.04	- - -	100.00	- - -
245	Rock Creek (Cloverly)	6	NE 3	19N	78W	15,702	6,207	- -	- -	- -	9,072	79	700	270.00	- - -	- - -	- - -	255.90	2.63	11.47	94.78	- - -	5.22	- - -	100.00	- - -
246	Rock Creek (Cloverly)	3	NE 11	19N	78W	6,534	2,642	- -	- -	- -	2,892	90	1,850	114.91	- - -	- - -	- - -	81.59	3.00	30.32	71.00	- - -	29.00	- - -	100.00	- - -
247	Rock Creek (Cloverly)	1	NE 11	19N	78W	7,328	2,962	- -	- -	- -	3,240	Tr	2,890	128.83	- - -	- - -	- - -	91.39	- - -	37.54	70.88	- - -	29.12	- - -	100.00	- - -
248	Rock Creek (Cloverly)	2	NE 34	20N	78W	14,039	5,584	- -	- -	- -	7,592	91	1,570	242.92	- - -	- - -	- - -	214.16	3.03	25.73	88.16	- - -	11.84	- - -	100.00	- - -
249	Rock Creek (Cloverly)	10	SE 34	20N	78W	10,916	4,148	106	22	- -	6,588	- -	105	180.45	5.29	1.81	- - -	185.83	- - -	1.72	96.22	2.86	- - -	0.92	100.00	- - -
250	Qasaly (Basal Cloverly)	4	18	17N	76W	1,552	620	Tr	- -	58	655	- -	145	26.98	- - -	- - -	1.21	18.47	- - -	7.30	72.94	- - -	27.06	- - -	93.86	6.14
251	Big Hollow (Upper Cl.)	1	32	16N	74W	967	378	- -	- -	184	171	- -	475	16.44	- - -	- - -	3.83	4.82	- - -	7.79	52.62	- - -	47.38	- - -	55.72	44.28
												POISON SPIDER AREA														
252	Bolton Creek (Dakota?)	1	NE 4	29N	81W	579	226	- -	- -	143	32	18	325	9.81	- - -	- - -	2.98	0.90	0.60	5.33	39.56	- - -	60.44	- - -	23.21	76.79
253	Bolton Creek (Dakota?)	8	NE 4	29N	81W	526	207	- -	- -	123	19	24	310	8.98	- - -	- - -	2.56	0.54	0.80	5.08	34.52	- - -	65.48	- - -	17.45	82.55
254	Spindletop (Dakota?)	1	SW 32	30N	81W	1,205	413	18	4	520	40	- -	440	17.94	0.90	0.33	10.83	1.13	- - -	7.21	62.40	- - -	31.40	6.20	9.30	90.70
255	North Platte (Dakota?)	1	NW 21	33N	80W	534	222	- -	- -	39	54	59	325	9.63	- - -	- - -	0.81	1.52	1.97	5.33	24.20	- - -	75.80	- - -	65.22	34.78
256	North Platte (Dakota?)	1	NW 21	33N	80W	424	183	- -	- -	- -	16	50	355	7.94	- - -	- - -	- - -	0.45	1.67	5.82	5.66	- - -	94.34	- - -	100.00	- - -
257	Iron Creek (Dakota?)	6	11	32N	82W	1,405	583	18	6	61	21	166	1,175	25.04	0.90	0.49	1.27	0.59	5.32	19.25	7.04	- - -	67.70	5.26	31.82	68.18
258	Poison Spider (Dakota?)	10	NE 12	33N	83W	944	349	6	- -	325	15	72	360	15.19	0.29	- - -	6.77	0.42	2.40	5.90	46.40	- - -	51.60	2.00	5.69	94.31
259	Notches (Dakota?)	1	SW 3	37N	85W	1,732	616	- -	- -	823	33	24	460	26.74	- - -	- - -	17.14	0.93	0.80	7.87	67.58	- - -	32.42	- - -	5.15	94.85
260	Notches (Dakota?)	1	NE 10	37N	85W	1,536	475	20	34	727	14	- -	540	20.65	1.00	2.82	15.20	0.40	- - -	8.87	63.28	- - -	21.38	15.34	2.60	97.40
261	N. Casper Creek (Dakota?)	4	NW 31	37N	81W	1,450	499	- -	- -	784	32	24	225	21.71	- - -	- - -	16.32	0.90	0.80	3.69	79.32	- - -	20.68	- - -	5.23	94.77
262	N. Casper Creek (Dakota?)	3	SE 36	37N	82W	1,771	607	- -	- -	981	28	30	255	26.40	- - -	- - -	20.43	0.79	1.00	4.18	80.38	- - -	19.62	- - -	3.72	96.28
												POWDER RIVER BASIN														
263	Salt Creek (Dakota)	36L	SW 26	40N	79W	13,009	5,131	38	6	42	6,850	- -	1,915	223.10	1.90	0.49	0.87	193.23	- - -	31.39	86.18	- - -	12.82	1.00	99.56	0.44
264	Salt Creek (Dakota)	19L	NW 25	40N	79W	9,403	3,690	30	12	82	5,150	- -	975	160.47	1.50	0.99	1.71	145.27	- - -	15.98	90.24	- - -	8.16	1.60	99.07	0.93
265	Salt Creek (Dakota)	1L	SE 34	40N	79W	14,399	5,561	56	18	137	7,750	- -	1,500	241.77	2.80	1.48	2.85	218.61	- - -	24.59	90.00	- - -	8.26	1.74	98.93	1.07
266	Salt Creek (Lakota)	10	SE 15	40N	79W	4,639	1,507	16	- -	58	674	229	2,327	65.54	0.80	- - -	1.21	19.00	7.63	38.50	30.46	- - -	68.34	1.20	94.09	5.91
267	Salt Creek (Lakota)	36L	NW 23	40N	79W	2,814	1,169	Tr	- -	12	750	Tr	1,795	50.83	- - -	- - -	0.25	21.16	- - -	29.42	42.08	- - -	57.92	- - -	98.89	1.11
268	Salt Creek (Lakota)	31L	NE 23	40N	79W	2,866	1,187	Tr	- -	- -	850	Tr	1,685	51.59	- - -	- - -	- - -	23.98	- - -	27.61	46.60	- - -	53.40	- - -	100.00	- - -
269	Salt Creek (Lakota)	16L	SW 23	40N	79W	3,828	1,558	Tr	- -	Tr	1,550	Tr	1,465	67.73	- - -	- - -	- - -	43.72	- - -	24.01	64.50	- - -	35.50	- - -	100.00	- - -
270	Salt Creek (Lakota)	16L	SW 23	40N	79W	2,568	1,048	12	Tr	Tr	800	Tr	1,440	45.57	0.60	- - -	- - -	22.57	- - -	23.60	48.80	- - -	49.90	1.30	100.00	- - -
271	Salt Creek (Lakota)	33L	SE 23	40N	79W	4,925	2,008	- -	- -	- -	1,928	30	1,950	87.35	- - -	- - -	- - -	54.39	1.00	31.96	62.26	- - -	37.74	- - -	100.00	- - -
272	Salt Creek (Lakota)	6L	SW 24	40N	79W	2,691	1,127	25	Tr	- -	265	Tr	2,610	49.01	1.25	- - -	- - -	7.48	- - -	42.78	14.80	- - -	82.72	2.48	100.00	- - -
273	Salt Creek (Lakota)	19L	SW 24	40N	79W	2,948	1,252	28	Tr	- -	340	Tr	2,700	52.45	1.40	- - -	- - -	9.59	- - -	44.26	17.80	- - -	79.60	2.60	100.00	- - -
274	Salt Creek (Lakota)	24L	NE 27	40N	79W	2,484	1,035	Tr	- -	Tr	690	- -	1,625	44.97	- - -	- - -	- - -	16.34	- - -	26.63	40.80	- - -	59.20	- - -	100.00	- - -
275	Salt Creek (Lakota)	36L	SE 27	40N	79W	3,432	1,393	Tr	- -	40	1,350	Tr	1,320	60.55	- - -	- - -	0.83	38.08	- - -	21.64	64.20	- - -	35.80	- - -	97.97	2.03

TABLE IV

DAKOTA GROUP WATERS (*Concluded*)

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
											POWDER RIVER BASIN			(Continued from Page 2)												
276	Salt Creek (Lakota)	22L	NW 26	40N	79W	1,703	696	7	Tr	Tr	525	--	965	30.28	0.35	---	---	14.81	---	15.82	48.60	---	50.26	1.14	100.00	---
277	*Salt Creek (Lakota)	18L	NW 25	40N	79W	6,440	2,677	Tr	--	64	1,600	268	3,680	116.38	---	---	1.33	45.13	9.60	60.32	39.94	---	60.06	---	97.15	2.85
278	Salt Creek (Lakota)	31L	NW 25	40N	79W	3,068	1,314	--	--	Tr	260	24	2,990	57.14	---	---	---	7.33	0.80	49.01	12.82	---	87.18	---	100.00	---
279	Salt Creek (Lakota)	7A	NE 25	40N	79W	2,521	1,017	6	--	--	139	195	2,098	44.51	0.30	---	---	3.92	6.50	34.39	8.61	---	90.66	0.70	100.00	---
280	*Salt Creek (Lakota)	1L	NE 34	40N	79W	4,321	1,808	--	--	45	1,350	Tr	2,415	78.60	---	---	0.94	38.08	---	39.58	49.60	---	50.40	---	97.59	2.41
281	Salt Creek (Lakota)	24	NE 34	40N	79W	1,562	634	20	Tr	12	300	--	1,210	27.58	1.00	---	0.25	8.46	---	19.87	30.40	---	66.20	3.40	97.37	2.63
282	*Salt Creek (Lakota)	13L	SW 35	40N	79W	4,024	1,662	--	--	--	1,257	60	2,125	72.29	---	---	---	35.46	2.00	34.83	49.06	---	50.94	---	100.00	---
283	Salt Creek (Lakota)	16L	NW 2	39N	79W	2,018	857	Tr	--	--	340	Tr	1,670	37.24	---	---	---	9.67	---	27.57	26.60	---	73.40	---	100.00	---
284	Salt Creek (Lakota)	25	NE 12	39N	79W	2,689	1,151	Tr	--	--	240	--	2,640	50.04	---	---	---	6.77	---	43.27	13.50	---	86.50	---	100.00	---
285	Midway (Lakota)	11	NE 23	35N	79W	2,805	1,114	8	--	521	107	386	1,360	48.62	0.40	---	10.85	3.02	12.86	22.29	28.30	---	70.88	0.82	21.77	78.23
286	Cole Creek (Lakota)	1	SE 21	35N	77W	6,237	2,280	67	--	1,321	2,080	--	995	99.16	3.34	---	27.51	58.68	---	16.31	84.08	---	12.66	3.26	68.09	31.91
287	Big Muddy (Lakota)	5	9	33N	76W	3,310	1,318	--	--	485	616	67	1,675	57.16	---	---	10.10	17.38	2.23	27.45	48.08	---	51.92	---	63.24	36.76
288	South Geary (Cloverly)	11	NW 32	34N	77W	593	236	--	--	127	9	Tr	450	10.27	---	---	2.64	0.25	---	7.38	28.14	---	71.86	---	8.68	91.32
289	Ant Hills (Fall River)	1	NE 25	37N	63W	1,343	520	15	7	50	350	Tr	795	22.62	0.75	0.58	1.04	9.87	---	13.03	45.20	---	49.40	5.40	91.10	8.90
290	Lance Creek (2nd Fall River)	4	SW 35	36N	65W	1,756	731	--	--	86	252	60	1,275	31.80	---	---	1.79	7.11	8.00	20.90	27.98	---	72.02	---	79.91	20.09
291	Lance Creek (1st Fall River)	2	NW 4	35N	65W	3,035	1,295	--	--	--	324	--	2,880	56.34	---	---	---	9.14	---	47.20	16.22	---	83.78	---	100.00	---
292	Lance Creek (1st Fall River)	2	SE 5	35N	65W	1,931	834	--	--	52	Tr	Tr	2,125	36.30	---	---	---	1.47	---	34.83	4.06	---	95.94	---	100.00	---
293	Wakeman Flats (Newcastle)	1	NW 20	49N	66W	1,170	487	--	--	--	310	--	760	21.19	---	---	---	8.74	---	12.45	41.24	---	58.76	---	100.00	---
294	Osage (Lakota)	4	NE 18	46N	61W	1,051	362	--	--	576	15	Tr	200	15.69	---	---	11.99	0.42	---	3.28	79.10	---	20.90	---	3.39	96.61
295	Osage (Lakota)	24	NE 24	46N	64W	760	257	--	--	355	8	--	215	11.14	---	---	7.39	0.23	---	3.52	68.40	---	31.60	---	3.02	96.98
296	Dewey Anticline (Cl.)	1	NW 7	41N	60W	1,064	372	--	--	544	25	--	250	16.14	---	---	11.33	0.71	---	4.10	74.60	---	25.40	---	5.90	94.10
297	W. Mule Creek (Cloverly)	2	NE 14	39N	61W	890	336	--	--	298	32	37	380	14.56	---	---	6.20	0.90	1.23	6.23	48.76	---	51.24	---	12.67	87.33
298	W. Mule Creek (Cloverly)	3	NE 14	39N	61W	813	338	--	--	63	70	37	620	14.67	---	---	1.31	1.97	1.23	10.16	22.36	---	77.64	---	60.06	39.94
299	W. Mule Creek (Cloverly)	1	NE 19	39N	60W	795	304	--	--	233	44	59	315	13.23	---	---	4.85	1.24	1.97	5.17	46.04	---	53.96	---	20.38	79.62

& Analyses courtesy Midwest Refining Company.
* Upper Lakota.

a primary alkaline type, with varying proportions of secondary alkalinity. Sulphate predominates in many of the more dilute waters, and calcium and magnesium are present in appreciable quantities in some.

The differences in concentration, and the presence of sulphate and the alkaline earths in the waters of the "Dakota group" serve to distinguish them from Frontier waters in the same area.

Where the Fuson shale, or its equivalent, is thin and the superjacent and subjacent sands are exposed in a well the analysis is that of water from the two sands and is called "Cloverly" in Table IV.

BIG HORN BASIN

Frannie oil field.—In the Frannie field about 100 feet of shale separates the basal sand of the Cloverly from the Greybull sandstone member. The well represented by analysis 213 was drilled as a water well and entered the Greybull sand for only five feet at a depth of 1,037 feet. Accordingly, this analysis is of a representative Greybull water, whereas the well represented by analysis 214 drilled into the basal Cloverly without casing off the Greybull water, and the sample is, therefore, classed as "Cloverly."

The Greybull water is essentially a solution of sodium sulphate and sodium bicarbonate, and is satisfactory for use in boilers and oil-field operations. The analysis of the mixed waters shows that the basal Cloverly water is far more dilute, and probably makes up the greater part of the flow in the second well. The sulphate content is about the same but takes up a greater percentage in the chemical system because of the lower concentration of the water. Secondary alkalinity is present, and the dissolved salt content of the Cloverly sample thus consists of 62 per cent sodium sulphate, 8 per cent sodium chloride, 4 per cent sodium bicarbonate, and 26 per cent calcium and magnesium bicarbonates.

No figures are available on the water flow in the Cloverly well, but if the quality of the basal water, as deduced from this one analysis, is correct, a good supply of potable water might be obtained from the basal sand.

The only other formation water sampled in Frannie wells comes from the Tensleep sandstone. No difficulty is encountered in distinguishing the two, however, as the Tensleep water is far more concentrated and contains 500–700 parts per million of calcium with large quantities of sulphate.

Torchlight field.—A Greybull sand water, similar chemically to the Greybull water of the Frannie field but more concentrated, is found at Torchlight. The Cloverly carries only water in this field and consists of 30 feet of Greybull sand, 150 feet of variegated shale, and 40 feet of basal sand.

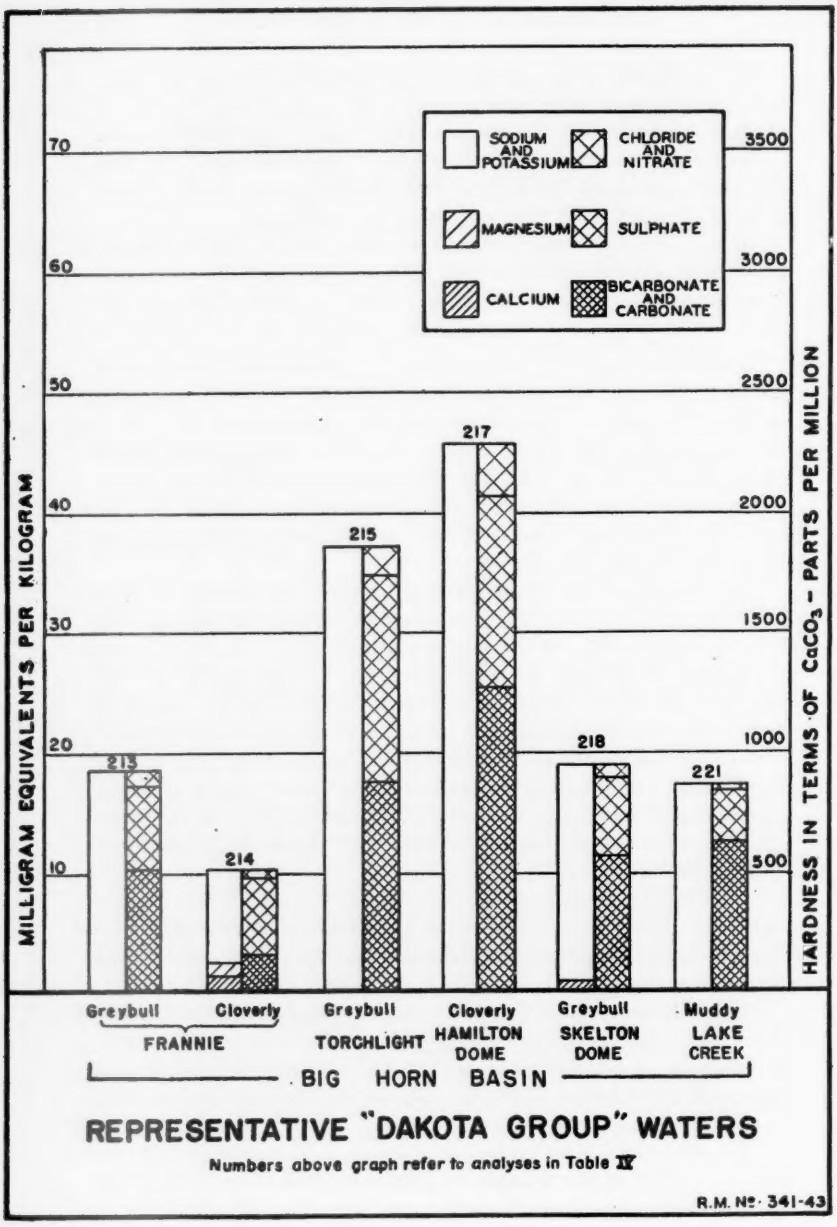

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
70
60
50
40
30
20
10
3500
3000
2500
2000
1500
1000
500
213
214
215
217
218
221
Greybull
Cloverly
FRANNIE
Greybull
TORCHLIGHT
Cloverly
HAMILTON DOME
Greybull
SKELTON DOME
Muddy
LAKE CREEK
BIG HORN BASIN
REPRESENTATIVE "DAKOTA GROUP" WATERS
Numbers above graph refer to analyses in Table IV
R.M. No. 341-43

FIG. 10

The well from which analysis 215 was obtained was drilled somewhat off structure and found the top of the Greybull sand at a depth of 1,570 feet, flowing 25 barrels of water a day. The only other water samples obtained from the Torchlight field were of the Madison limestone artesian water, which can be distinguished from the Greybull water by its extremely low concentration of less than 300 parts per million.

Hamilton dome.—The Cloverly formation at Hamilton dome consists of three beds of sandstones separated by variegated shales, described in well logs as red shale, with showings of oil reported in the basal sand. All sands carry water and have not been distinguished by water analyses. The analyses from this formation in Hamilton dome are classified simply as "Cloverly" water.

The two wells from which analyses 216 and 217 were taken are on the axis of the structure and on the downthrown side of a fault. The top of the water sand was found at 900 feet. This water is the most concentrated "Dakota group" water in the Big Horn Basin, indicating a more stagnant water condition than elsewhere in the basin, probably caused by its location with respect to the fault. Primary alkalinity and primary salinity are about equal, and 80 per cent of the salinity is due to sulphate.

Other formation waters encountered at Hamilton dome are in the Chugwater, Embar, and Tensleep, all of which may be distinguished from the Greybull water by their much higher concentration and presence of the alkaline earths.

Skelton dome.—The log of the one well on Skelton dome shows the Greybull sand to be 93 feet thick and the basal sand of the Cloverly 44 feet thick, with 166 feet of red shale between. No information is available as to the casing in this well, but it is known that the first water sample (218) was obtained at a depth of 3,505 feet, the second at a depth of 3,530 feet, and the third at a depth of 3,570 feet, all in the Greybull sand.

Lake Creek field.—The only sample from the Muddy sand in the Big Horn Basin was obtained at Lake Creek on the extreme southeastern edge of the basin. The Muddy sand in this area is about 80 feet thick and consists of variable thin sands with shale breaks. The top of the sand was logged at 625 feet, and water was encountered in the first 6 feet and in the last 60 feet. An artesian flow of 4,000 barrels a day was encountered and the well was saved as a water well.

The water is dilute and contains sodium sulphate and sodium bicarbonate in a ratio of one to three. The water is suitable for all oil-field operations, irrigation, and domestic use.

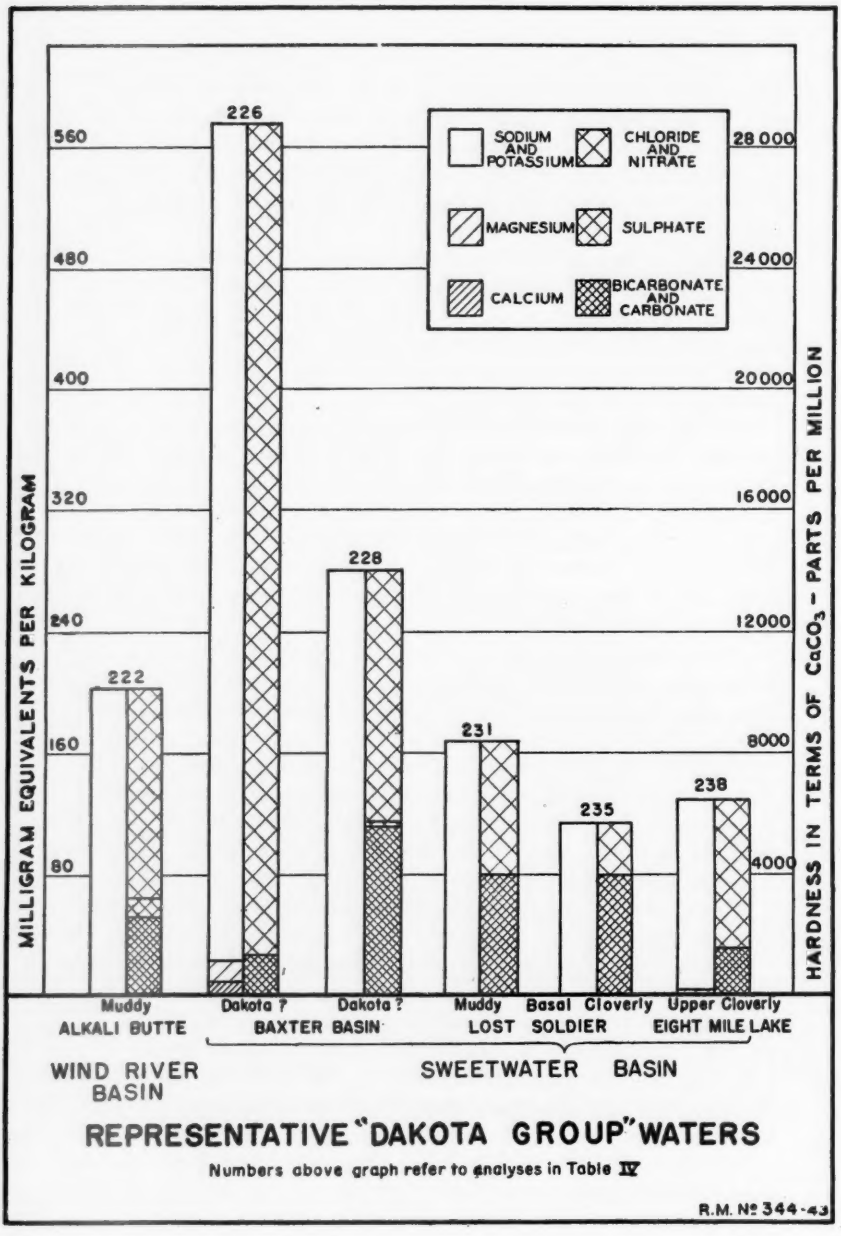

MILLIGRAM EQUIVALENTS PER KILOGRAM
560
480
400
320
240
160
80
226
222
228
231
235
238
SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
28 000
24000
20000
16000
12000
8000
4000
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
Muddy
ALKALI BUTTE
Dakota ?
Dakota ?
BAXTER BASIN
Muddy
LOST
Basal Cloverly
SOLDIER
Upper Cloverly
EIGHT MILE LAKE
WIND RIVER BASIN
SWEETWATER BASIN
REPRESENTATIVE "DAKOTA GROUP" WATERS
Numbers above graph refer to analyses in Table IV
R.M. Nº 344-43

FIG. 11

WIND RIVER BASIN

Alkali Butte field.—The only "Dakota group" water sampled in Wind River Basin was from the Muddy sand in the Alkali Butte field. The top of the sand was logged at 4,245 feet and six feet of it produced water at the rate of 500 barrels a day. One well struck oil in the Muddy sand with an initial production of 400 barrels a day, but rapidly dropped to 4 or 5 barrels a day. The oil was found on the structural "high," those wells lower on the structure finding only water in the Muddy sand.

The water is a primary saline type and its high concentration suggests little circulation in the sand. It resembles the higher concentrated Frontier water in this field, but contains sulphate and has a lower bicarbonate content than the Frontier.

It differs from the Mesaverde water in its higher concentration and the absence of the alkaline earths, and from Steele shale waters by the presence of sulphate.

SWEETWATER BASIN

Baxter Basin fields.—The Dakota (?) sandstone in the Baxter Basin fields consists of two to four sandstone members each varying in thickness from 4 to 90 feet, separated by gray and black shale and sandy shale. The "Dakota group" lies unconformably on the Morrison formation, and its thickness varies from 90 to 225 feet. The Dakota (?) produces sweet gas in North Baxter and sour gas in South Baxter Basin.

As pointed out in discussing the Frontier waters of this field, severe faulting has affected the concentration and constituents of the various waters and to some extent has permitted the migration of water from one formation to another. This is particularly true of the Sundance and Dakota (?) waters.

The eight typical Dakota (?) waters listed in Table IV are from water wells free of gas. In North Baxter Basin the waters are definitely saline, ranging from 90 to 97 per cent primary salinity, with an average concentration of 16,000 parts per million, excluding analysis 226. Definite quantities of sulphate and the alkaline earths are present in all these waters.

In Middle Baxter Basin the salinity of the Dakota (?) water drops to 60 per cent and the alkalinity increases to 40 per cent. Sulphate is low and may be present only as drilling-water contamination. The alkaline earths are absent.

In South Baxter Basin the concentration of the Dakota (?) water decreases to an average of 9,000 parts per million, although the rela-

tive salinity and alkalinity are about the same as in Middle Baxter Basin. Small quantities of alkaline earths are present, and sulphate is either absent or appears only as drilling-water contamination. Hydrogen sulphide is present in analysis 230, the only "Dakota group" water to contain this gas, because the Dakota (?) gas in South Baxter Basin contains 30–70 grains of hydrogen sulphide per 100 cubic feet of gas.

The Dakota (?) waters in Baxter Basin can be distinguished from Frontier waters by their lower concentration and the presence of sulphate. However, correlations should be made with wells in the immediate vicinity to insure accuracy, as Dakota (?) waters in one section of the field may appear similar to Frontier or Sundance waters in another area. Analysis 226 is unquestionably Dakota (?) water, but in concentration and chemical constituents correlate closely with Frontier water. This may be due to its position with respect to a fault, and shows the difficulty encountered in correlation in this field.

Lost Soldier field.—The "Dakota group" is about 240 feet thick in the Lost Soldier field. The Muddy sand is 40 feet thick and the subjacent shale 105 feet thick. The upper sandstone of the Cloverly is about 50 feet thick and contains one shale bed 8 feet thick. The 35-foot basal bed of the Cloverly is separated from the upper bed by 10 feet of shale. The Muddy sand and the basal Cloverly sand produce oil, and in places some oil is found in the upper Cloverly sand. The top of the Muddy sand lies about 1,900 feet below the surface.

The Muddy sand water at Lost Soldier is easily distinguished by its higher concentration and salinity. The upper Cloverly water is the most dilute water in the group and is distinguishable from basal Cloverly water by its lower bicarbonate content. The basal Cloverly water, though very similar to that in the upper Cloverly, contains more bicarbonate and definite proportions of sulphate.

Excepting analysis 235, the basal Cloverly waters in Table IV may have mingled to some extent with upper Cloverly waters.

"Dakota group" waters can be distinguished from Frontier waters by their lower concentration and by the presence of sulphate in basal Cloverly water. The Sundance water in this area is very similar to the upper Cloverly water and can be distinguished only by its slightly lower bicarbonate content.

Eight Mile Lake anticline.—The top of the Muddy sand in the Eight Mile Lake anticline lies at an average depth of 3,800 feet. The "Dakota group" consists of 20 feet of Muddy sand, 75 feet of shale, and 95 feet of Cloverly sand with no shale break.

Gas production in the Eight Mile Lake field comes from the top

of the Cloverly, but one well produces gas from the Muddy, probably originating in the Cloverly and migrating upward along a fault. From this well came analysis 237, which is a concentrated saline water with only 3 per cent alkalinity. The evaporative effect of the expanding gas may be a factor in its high concentration.

The gas production in the upper Cloverly sand is accompanied by water which differs from that in the Muddy sand by having lower primary salinity, absence of secondary salinity, and by the presence of primary alkalinity. The two waters can be easily distinguished by their concentration and bicarbonate content, and can be differentiated from the Frontier water by their much higher concentration.

LARAMIE BASIN

East Rock River area.—Four dry holes have been drilled in the East Rock River area and water samples were obtained from one, which found the upper Cloverly sand at depths of 1,835–1,839 feet, and the lower Cloverly sand at 1,895–1,905 feet. These samples were obtained by plugging back and shooting the $4\frac{3}{4}$-inch casing with Lane-Wells guns, and it is believed, therefore, that they are representative.

The upper Cloverly water is a primary alkaline type, dilute, and usable in oil-field operations and for domestic purposes. Primary salinity is prominent in the lower Cloverly water, which is the reverse of conditions in the upper and serves to differentiate them. The lower Cloverly water is slightly more dilute than the upper and also usable for domestic purposes.

Rock Creek oil field.—The "Dakota group" in the Rock Creek oil field lies about 3,200 feet below the surface and consists of 45 feet of Muddy sand, 55 feet of shale, 40 feet of upper Cloverly sand, 10 feet of shale, and 65 feet of basal Cloverly sand. All sands in the "Dakota group" contain oil and gas.

In this field all wells are bottomed in the basal Cloverly sand and all exposed sands of the "Dakota group" are protected by liners perforated opposite the sands. For this reason a water can not be definitely correlated with a particular sand, and the concentration and relative proportions of the radicles will vary according to which sand is producing the most water at that time.

Water samples are collected in the Rock Creek field in order to differentiate the oil-producing Sundance formation, the water from it being far more dilute than the "Dakota group" waters, and also containing an appreciable quantity of sulphate.

Quealy oil field.—In the discovery well in the Quealy field, the top of the "Dakota group" was logged at 3,146 feet; the average

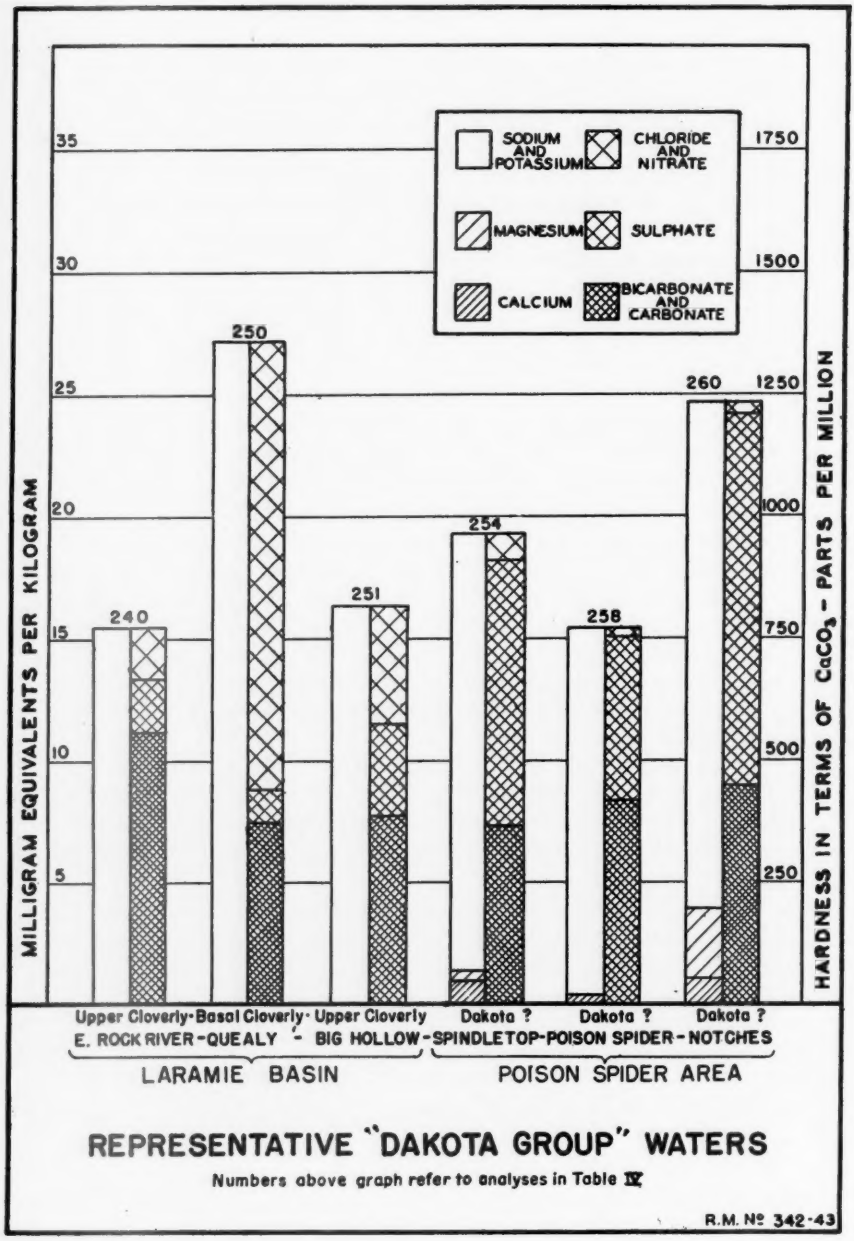

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
35
30
25
20
15
10
5
1750
1500
1250
1000
750
500
250
240
250
251
254
258
260
Upper Cloverly
Basal Cloverly
Upper Cloverly
Dakota ?
Dakota ?
Dakota ?
E. ROCK RIVER - QUEALY - BIG HOLLOW - SPINDLETOP - POISON SPIDER - NOTCHES
LARAMIE BASIN
POISON SPIDER AREA
REPRESENTATIVE "DAKOTA GROUP" WATERS
Numbers above graph refer to analyses in Table IX
R.M. № 342-43

FIG. 12

thickness of the Cloverly formation in the field is 84 feet. The Muddy sand is tightly cemented in some sections of the field and contains showings of oil. The upper Cloverly sand is the principal oil zone.

The well from which analysis 250 was obtained drilled through the oil-saturated upper Cloverly sand into the partially saturated basal sand. The sample was then obtained and the well plugged back into the upper sand, shutting off the water.

The water in the Quealy field is of the primary saline type, 90 per cent of the salinity being due to chloride, and in chemical composition resembles the "Dakota group" waters in the Rock Creek field, though more dilute. The low concentration suggests fairly rapid water movement in the sand.

Big Hollow structure.—In and near the Big Hollow structure the sands of the "Dakota group" are very thin in some places and elsewhere are about 300 feet thick, lying about 700 feet below the surface.

The well from which analysis 251 came is bottomed in the upper Cloverly sand and is used as a water well. The water is roughly equal in primary salinity and primary alkalinity, is dilute, and is fair for domestic use. The salinity is about equally divided between sulphate and chloride.

POISON SPIDER AREA

Bolton Creek field.—The Muddy sand is not present in the Bolton Creek field. The top of the Dakota (?) sandstone is reached at a depth of about 850 feet and, together with the inseparable subjacent basal Cloverly sand, is about 90 feet thick.

The sands of the "Dakota group" crop out on the Bates Park anticline, 8 miles from the Bolton Creek field, and near Alcova, 12 miles distant, with the result that they furnish a strong flow of potable water at Bolton Creek. The water is of the primary alkaline type and is easily distinguishable from Sundance water by its low concentration.

Spindletop dome.—The Spindletop field lies about two miles west of the Bolton Creek field. The top of the Dakota (?) sandstone is found at a depth of 555 feet and the bottom of the "Dakota group" at 632 feet.

Although the water in the sands of the "Dakota group" at Spindletop is twice as concentrated as at Bolton Creek, it is used for livestock and for domestic purposes. Wells on the flanks of the dome yield a strong flow of water, but those on the crest do not flow, though the water reaches the surface. The former wells have a lower surface elevation than crest wells by more than 50 feet.

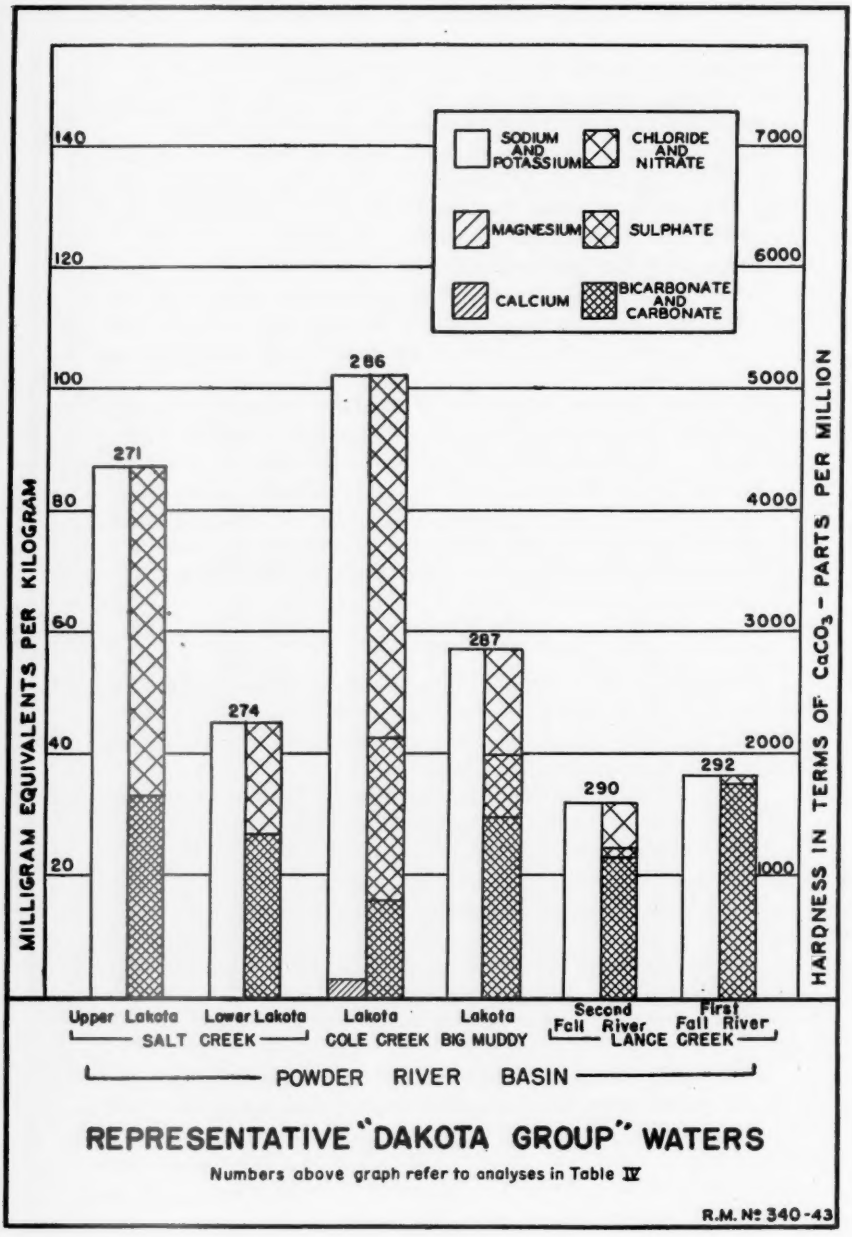

MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ – PARTS PER MILLION
140
120
100
80
60
40
20
7000
6000
5000
4000
3000
2000
1000
SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
271
274
286
287
290
292
Upper Lakota
Lower Lakota
Lakota
Lakota
Second Fall River
First Fall River
SALT CREEK
COLE CREEK
BIG MUDDY
LANCE CREEK
POWDER RIVER BASIN
REPRESENTATIVE "DAKOTA GROUP" WATERS
Numbers above graph refer to analyses in Table IV
R.M. Nº 340-43

FIG. 13

The "Dakota group" water at Spindletop has greater salinity than at Bolton Creek, and is distinguished from Sundance water by its lower concentration.

North Platte structure.—The first well drilled on the North Platte structure found 10 feet of Dakota (?) sandstone at a depth of 1,345 feet, which initially flowed 1,000 barrels of potable water daily. Later the well had a settled daily flow of 200 barrels of water.

The water in this North Platte well is of the primary alkaline type with but little sulphate, differing in this latter respect from most of the Dakota (?) waters in the Poison Spider area.

Iron Creek field.—The Iron Creek field is about 8 miles southeast of the Poison Spider field and on the same anticline. The top of the Dakota (?) sandstone was reached at a depth of 738 feet in the Iron Creek field and the bottom at 846 feet. This sandstone yields mainly water, with a little oil. Primary alkalinity dominates the chemical system, and the water is unusual for Dakota (?) waters in this area because of its large proportion of bicarbonate.

Poison Spider field.—In the Poison Spider field the top of the Dakota (?) sandstone is logged at an average depth of 805 feet and the bottom at 905 feet. Oil production is from a sand in the Sundance formation.

The flowing well from which analysis 258 was obtained was plugged back from the Sundance to the Dakota (?) sandstone. The Sundance water in this field can be distinguished from the dilute, potable Dakota (?) water by its greater concentration and higher bicarbonate content.

Notches field.—The Dakota (?) sandstone is logged at depths of 929–982 feet in the Notches field and yields a daily artesian flow of 1,000 barrels of water. The well from which analysis 260 came produces oil from the Tensleep sandstone and water from the Dakota (?) sandstone.

The water is saline because of the sulphate radicle and, though too concentrated to be potable, is satisfactory in oil-field operations. It is much more dilute and has a much lower chloride content than Tensleep water in the field.

North Casper Creek field.—The Dakota (?) sandstone in the North Casper Creek field yields artesian water similar to that in the Notches field. The sand occurs at a depth of 1,465–1,525 feet. The well from which analysis 262 was obtained pumps oil from the Tensleep sandstone and flows 5,000 barrels of water daily from the Dakota (?) sandstone through the bradenhead.

POWDER RIVER BASIN

Salt Creek area.—The "Dakota group" in the Salt Creek area averages about 6 feet of Muddy sand, 200 feet of dark shale, 10 feet of Dakota sand, 70 feet of shale, and 70 feet of Lakota sand which consists of sandstone beds separated by thin layers of shale. The Muddy sand is variable and remnants only are found in some areas.

The Dakota sand ranges from an inch to about 14 feet in thickness and contains small amounts of oil and gas with water. The Dakota water is essentially a solution of sodium chloride with small percentages of sulphate, bicarbonate, and the alkaline earths, and is thus distinguishable from the Frontier waters of this area. The Second Wall Creek sand water resembles Dakota water somewhat in concentration, but the lower bicarbonate of the latter distinguishes them.

The Lakota sand is the principal oil producer of the "Dakota group," and consists of two strata of conglomerate and sandstone, sometimes separated by an impermeable shale member. As the Lakota sand is porous and highly permeable locally, many wells had initial flows varying from 1,000 to 5,000 barrels of oil a day.

The Lakota waters are similar to First Wall Creek sand waters, and are essentially solutions of sodium bicarbonate and sodium chloride. Waters in the upper Lakota contain more than twice as much chloride as in the lower Lakota, but the bicarbonate content is the same. The average chloride content of the upper water is 1,400 parts per million, that of the lower 400 parts per million.

The nearest counterpart in this area to the Lakota waters are some of the First Wall Creek sand waters, but a comparison of individual wells in the productive Lakota area shows that the concentration of the Lakota water is about 60 per cent of that from the First Wall Creek sand.

Lower concentration of the Lakota water indicates much freer water movement in that sand than in the First Wall Creek sand.

Midway structure.—The Muddy is the only sand of the "Dakota group" to produce oil at Midway. It was logged in one well at 5,967–5,983 feet, followed by 11 feet of shale, and 83 feet of undifferentiated Dakota and Lakota. The Lakota water sampled in this well is essentially a solution of sodium bicarbonate and sodium sulphate with a small quantity of sodium chloride, differing from the Second Wall Creek sand water hereinbefore discussed in its lower concentration and in the presence of the dominant sulphate radicle. A much freer water movement exists in the Lakota sand than in the oil-producing Second Wall Creek sand.

Cole Creek structure.—The upper part of the Dakota sand was logged at depths of 7,921–7,944 feet in one well on the Cole Creek

structure. Above the Dakota sand five feet of shale and sand streaks probably represent the Muddy sand. Oil showings were found in the Dakota sand.

The important oil production at Cole Creek is from the Lakota sand, at depths of 7,975–8,015 feet, and 6 per cent of the total production is water. The water is a saline type, 68 per cent of the salinity being caused by the sulphate radicle, and it is the only highly saline Lakota water sampled in the Powder River Basin.

The Frontier and Lakota waters are readily distinguished by the presence of sulphate in the latter water, and its lower concentration.

Big Muddy oil field.—The "Dakota group" sands produce but little oil in the Big Muddy field. Oil has been found in the Muddy sand, two wells produce from the Dakota sand, and two wells produce oil and water from the Lakota sand.

The sands of the "Dakota group" are logged about as follows in this field: Muddy sand at 4,210–4,215 feet; Dakota sand at 4,276–4,281 feet; and Lakota sand at 4,362–4,406 feet. The well represented by analysis 287 is bottomed in the Lakota, the Dakota sand being cased off.

The Lakota water in analysis 287 is about equal in salinity and alkalinity and is distinguished from upper waters previously discussed by the presence of appreciable quantities of sulphate and a much lower concentration.

South Geary dome.—Two wells have been drilled on South Geary dome and neither oil nor gas was found. An artesian flow of 5,000 barrels a day of potable water was found in the Cloverly formation in the well from which analysis 288 was obtained. Although both the Dakota and Lakota sands were exposed in this well, most of the water comes from the latter. The Muddy sand was logged at 6,092–6,105 feet, the Dakota at 6,155–6,175 feet, and the Lakota at 6,188–6,210 feet, where the well was bottomed.

The water at South Geary is of the primary alkaline type, chemically similar to the water of the same sand at Midway, but far more dilute. The low concentration of this water indicates an unrestricted water flow in the sand and the consequent absence of oil. The salinity present is largely caused by the sulphate radicle, and the water is suitable for all oil-field operations and for domestic use.

Ant Hills structure.—The Ant Hills structure lies along the Hartville uplift, just north and east of the Lance Creek oil field, and produced some oil from the Newcastle sand (equivalent to the Muddy) at a depth of 3,995 feet, while drilling. Analysis 289 was obtained from the Fall River sandstone (Dakota of many reports).

The Fall River water at Ant Hills is more dilute and more saline

than the same water in the Lance Creek oil field, and the alkalinity is slightly greater than the salinity, resembling other Dakota waters in the Powder River Basin. As the sulphate radicle is present only in small amounts, the water resembles the practically sulphate-free Fall River water at Lance Creek. The water is suitable for boilers and condensing purposes in oil-field operations.

Lance Creek oil field.—The "Dakota group" averages 350 feet in thickness in the Lance Creek area. The Newcastle sandstone, where logged, is ordinarily productive of oil on the crest of the structure, and occurs about 3,000 feet under the surface. About 175 feet below the Newcastle are found the Fall River sands of which the first two are productive of oil, gas, or water. About 130 feet below the top of the first Fall River sand is the Lakota sand, which is productive of oil, gas, or water, according to the structural position of the well. The sands of the "Dakota group" are now depleted, and water samples are necessary only to identify intrusive Cloverly water in oil-producing Sundance and Minnelusa wells.

Three typical Fall River water analyses are given in Table IV. The second Fall River water (290) was produced with oil and is distinguished by its lower concentration and the presence of sulphate. First Fall River water is sulphate-free, somewhat more concentrated, with lower chloride and higher bicarbonate, as can be seen by comparing analyses 290 and 292. Analysis 291 is from a flooded gas well and its higher concentration is probably caused by the evaporative effect of expanding gas. Analysis 292 is a typical first Fall River water associated with oil in an edge well.

Fall River waters can be easily distinguished from the more important Sundance and Minnelusa waters by their lower concentration and the almost total absence of the sulphate radicle so prominent in the lower waters.

Wakeman Flats area.—Only one sample of Newcastle water was obtained in northeastern Wyoming; namely, in the Wakeman Flats area at a depth of 2,040 feet. The hole from which this sample came was abandoned in the Lakota sand. The water is alkaline and sulphate-free, which distinguishes it from other "Dakota group" waters in this area.

Osage oil field.—The Osage oil field is a terraced monocline dipping southwestward into the Powder River Basin. All "Dakota group" sands crop out a short distance east of the field and are fed by surface waters from the west slope of the Black Hills uplift. The Newcastle sandstone produces some gas and all the oil except some shallow shale oil in the northeastern part of the field. The Fall River sandstone

carries water, which has not been sampled, and gas in some parts of the field. An adequate supply of potable water is produced from the Lakota sandstone.

Analysis 294, Table IV, comes from the east side of the Osage field at a well depth of 890 feet, and analysis 295 from the center of the field at a well depth of 1,792 feet. In the latter well the Lakota sandstone yielded 5,000 barrels of water a day. These two analyses show representative extremes in concentration, the eastern well producing a water slightly higher in sodium sulphate. The Lakota water is essentially a solution of sodium sulphate and sodium bicarbonate, 70 per cent of the chemical system being sodium sulphate. The water is potable and very satisfactory for boiler use.

Shale and surface gravel waters, although chemically comparable to Lakota water, can be distinguished by their higher concentration which averages 2,200 parts per million. The Greenhorn water contains negligible amounts of sulphate and has a concentration of more than 15,000 parts per million. Stray-sand waters commonly encountered in this field can also be differentiated by their higher concentration.

Dewey anticline.—An artesian flow of 8,000 barrels a day was encountered in the Fall River sandstone and subjacent "Dakota group" beds in a well on the Dewey anticline. The Newcastle sand was missing. The Fall River was logged at 335–410 feet, and the Lakota at 425–545 feet. The hole was open to both sands, but it is thought that the Lakota produced most of the water. The water compares very closely with the Lakota water in the Osage field (294) and is satisfactory for all oil-field operations.

West Mule Creek oil field.—Potable water is produced from the Fall River and Lakota sandstones in the West Mule Creek field at a depth of 780–975 feet, the two sands lying so close together that they are left open in the hole.

Other Fall River-Lakota waters sampled in northeastern Wyoming are of the primary saline type, but the trend at West Mule Creek is more to the alkaline type, representing the change of the saline water of the Osage field to the alkaline water of the Lance Creek field. The West Mule Creek water is potable and very satisfactory as a boiler water in oil-field operations.

SUMMARY

"Dakota group" waters, irrespective of concentration, fall naturally into two classes: (1) those whose salinity is caused largely by the chloride radicle; (2) those whose salinity is caused more by the sulphate radicle than by the chloride. In general, waters of the first class

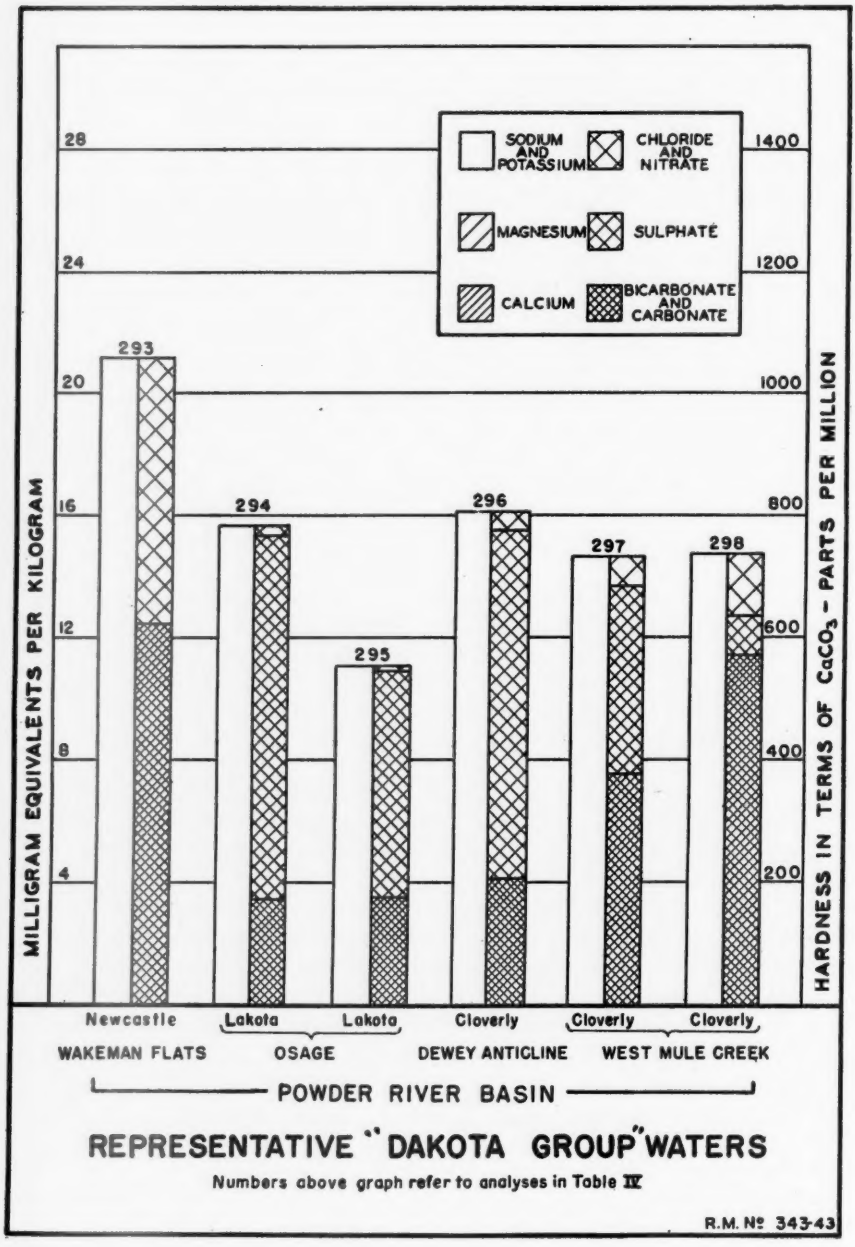

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
28
24
20
16
12
8
4
1400
1200
1000
800
600
400
200
293
294
295
296
297
298
Newcastle
Lakota
Lakota
Cloverly
Cloverly
Cloverly
WAKEMAN FLATS
OSAGE
DEWEY ANTICLINE
WEST MULE CREEK
POWDER RIVER BASIN
REPRESENTATIVE "DAKOTA GROUP" WATERS
Numbers above graph refer to analyses in Table IV
R.M. № 343-43

FIG. 14

occur where the sands of the "Dakota group" are deeply buried, and those of the second class where they lie at relatively shallow depths.

Primary salinity and alkalinity dominate the waters of the "Dakota group" and secondary alkalinity occurs rather often, ranging from a trace to 26 per cent. The concentration ranges from 30,000 parts per million to less than 500, with artesian flows of potable water occurring in many areas.

In the Big Horn Basin all sands of the "Dakota group" discussed herein were logged at depths of less than 2,000 feet, except at Skelton dome where the Greybull sand occurs at a depth of 3,500 feet, and the waters are of the sulphate-saline type. Primary alkalinity slightly exceeds salinity, and secondary alkalinity is found in the Greybull sand waters at Skelton dome. The concentration ranges from 500 parts per million at Skelton dome to 2,700 parts per million at Hamilton dome.

The "Dakota group" water in the Alkali Butte field is of the chloride-saline type, encountered at a depth of 4,200 feet. The water resembles a Frontier water but carries appreciable quantities of sulphate.

Chloride-saline "Dakota group" waters of high concentration occur in the Sweetwater Basin, the concentration varying between 33,000 parts per million at Baxter Basin to 4,000 parts per million in Lost Soldier. Primary salinity predominates at Baxter Basin, and primary alkalinity at Lost Soldier.

Chloride-saline Cloverly water occurs in the Laramie Basin, except at the extreme north and south edges of the basin, where potable sulphate-saline water is found. Primary salinity predominates, except in the upper Cloverly sand in the East Rock River area, which contains 71 per cent primary alkalinity. The concentration varies from 20,000 to 600 parts per million, the higher concentrated water being found in the Rock Creek oil field.

Artesian water of good quality occurs in the relatively shallow (less than 1,500 feet) Dakota (?) sandstone of the Poison Spider area. The water is generally of the sulphate-saline type and the concentration varies from 400 parts per million in the North Platte field to 1,700 parts per million in the Notches and North Casper Creek fields. A primary alkaline water is present in the fields south and west of the Poison Spider field, and a primary saline water in fields to the north and east.

Chloride-saline "Dakota group" waters are the rule in the south and west parts of the Powder River Basin, although the sulphate-saline type occurs in the Midway and South Geary fields, the only

TABLE V

Sundance Formation Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
											BICARBONATE WATER														
300	North Baxter Basin	1	SW 11	20N	10W	30,399	11,361	326	121	905	17,160	- -	1,070	494.21	16.27	9.95	18.84	484.05	- - -	17.54	94.96	1.68	- - -	3.36	96.28	3.75
301	North Baxter Basin	1	SW 11	20N	10W	6,217	2,022	269	27	1,469	1,560	- -	1,770	87.94	13.43	2.22	30.59	43.99	- - -	29.01	72.00	- - -	12.90	15.10	58.98	41.02
302	North Baxter Basin	1	NE 2	19N	10W	49,950	18,560	348	252	3,407	26,970	- -	840	807.37	17.37	20.72	70.92	860.77	- - -	13.77	95.50	2.86	- - -	1.64	91.48	8.52
304	North Baxter Basin	1	NE 24	19N	10W	16,292	6,350	36	41	872	7,124	- -	750	682.39	6.09	13.98	56.90	633.27	- - -	12.29	97.14	1.12	- - -	1.74	91.75	8.25
305	North Baxter Basin	1	SW 18	19N	10W	16,960	6,819	Tr	- -	159	7,696	- -	3,800	276.23	1.80	3.37	18.16	200.96	- - -	62.28	77.86	- - -	20.28	1.86	91.70	8.30
306	North Baxter Basin	1	SW 18	19N	10W	15,893	6,082	62	31	1,737	6,240	- -	3,540	264.56	3.09	2.55	36.16	176.02	- - -	98.02	78.52	- - -	19.40	2.08	82.95	17.04
307	North Baxter Basin	1	SW 18	19N	10W	12,902	5,288	23	Tr	151	3,900	- -	7,200	230.01	1.15	- - -	3.14	110.01	- - -	118.01	48.94	- - -	50.86	0.50	97.24	2.76
308	North Baxter Basin	1	SW 18	19N	10W	12,388	5,068	25	Tr	163	3,744	Tr	6,850	220.44	1.25	- - -	3.81	105.61	- - -	112.27	49.36	- - -	50.08	0.56	96.81	3.19
309	*North Baxter Basin	1	SW 18	19N	10W	7,905	3,069	82	Tr	451	2,964	- -	2,720	133.49	4.09	- - -	9.39	83.61	- - -	44.58	67.60	- - -	29.42	2.98	89.90	10.10
310	*North Baxter Basin	1	SW 18	19N	10W	9,476	3,729	122	Tr	- - -	3,744	- -	3,825	162.21	6.09	- - -	- - -	105.61	- - -	62.69	62.76	- - -	33.62	3.62	100.00	- - -
311	*North Baxter Basin	1	SW 18	19N	10W	10,289	4,006	101	52	16	4,004	- -	4,280	174.27	5.04	4.28	0.33	112.94	- - -	70.32	61.70	- - -	33.22	5.08	99.70	0.30
312	*South Baxter Basin	1	10	16N	10W	7,876	3,162	12	Tr	153	3,250	64	2,510	137.52	0.60	- - -	3.18	91.67	2.13	41.14	68.68	- - -	30.88	0.44	96.65	3.35
313	Lost Soldier	68	10	26N	90W	3,992	1,649	15	- -	- - -	996	- -	2,710	71.76	0.75	- - -	- - -	28.10	- - -	44.41	38.76	- - -	60.20	1.04	100.00	- - -
314	Lost Soldier	61A	10	26N	90W	3,841	1,591	Tr	- -	38	1,050	180	2,000	69.19	- - -	- - -	0.79	29.62	6.00	32.78	43.94	- - -	56.06	- - -	97.40	2.60
315	Lost Soldier	35	NW 11	26N	90W	4,278	1,786	- -	- -	- - -	1,051	- -	2,930	77.67	- - -	- - -	- - -	29.65	- - -	48.02	38.18	- - -	61.82	- - -	100.00	- - -
316	Lost Soldier	47	NW 11	26N	90W	3,800	1,546	22	Tr	32	1,100	- -	2,235	67.23	1.10	- - -	0.67	31.03	- - -	36.63	46.40	- - -	52.00	1.60	97.93	2.07
											LARAMIE WATER															
317	Allen Lake	2	NW 34	23N	79W	2,433	996	- -	- -	67	738	50	1,185	43.31	- - -	- - -	1.40	20.82	1.67	19.42	51.32	- - -	48.68	- - -	93.67	6.33
318	Medicine Bow	1	NE 23	21N	79W	1,889	733	- -	- -	447	221	50	890	31.80	- - -	- - -	9.31	6.23	1.67	14.99	48.88	- - -	51.12	- - -	40.10	59.90
319	Medicine Bow	6	NW 23	21N	79W	1,220	484	- -	- -	328	177	49	410	20.17	- - -	- - -	6.83	4.99	1.63	6.72	58.60	- - -	41.40	- - -	42.21	57.79
320	Medicine Bow	1	NW 25	21N	79W	1,774	699	- -	- -	399	152	Tr	1,075	30.22	- - -	- - -	8.31	4.29	- - -	17.62	41.70	- - -	58.30	- - -	34.06	65.94
321	Medicine Bow	1	NW 25	21N	79W	1,824	625	- -	- -	436	130	79	720	27.18	- - -	- - -	9.08	3.67	2.63	11.80	46.90	- - -	53.10	- - -	28.77	71.23
322	Medicine Bow	1	NW 25	21N	79W	1,788	699	- -	- -	408	196	50	965	30.39	- - -	- - -	8.50	4.40	1.67	15.82	42.44	- - -	57.56	- - -	34.10	65.90
323	Medicine Bow	4	SW 25	21N	79W	1,673	655	- -	- -	386	118	54	935	28.49	- - -	- - -	8.04	3.33	1.80	15.32	39.90	- - -	60.10	- - -	29.27	70.73
324	Medicine Bow	1	NE 26	21N	79W	2,922	1,117	- -	- -	761	395	24	1,270	48.60	- - -	- - -	15.84	11.14	0.80	20.82	55.52	- - -	44.48	- - -	41.30	58.70
325	Medicine Bow	2	NE 26	21N	79W	1,664	669	- -	- -	401	140	24	915	28.10	- - -	- - -	8.35	3.95	0.80	15.00	43.78	- - -	56.22	- - -	32.13	67.87
326	Medicine Bow	2	NE 26	21N	79W	1,400	554	- -	- -	279	120	Tr	910	24.10	- - -	- - -	5.81	3.38	- - -	14.91	38.14	- - -	61.86	- - -	36.79	63.21
327	Medicine Bow	2A	NE 26	21N	79W	1,317	522	- -	- -	258	104	Tr	880	22.72	- - -	- - -	5.37	2.93	- - -	14.42	36.54	- - -	63.46	- - -	35.32	64.68
328	Medicine Bow	3A	NE 26	21N	79W	1,477	576	- -	- -	348	125	30	810	25.05	- - -	- - -	7.25	3.53	1.00	13.27	43.02	- - -	56.98	- - -	32.72	67.28
329	Medicine Bow	4A	NE 26	21N	79W	2,149	834	- -	- -	508	229	37	1,100	36.30	- - -	- - -	10.58	6.46	1.23	18.03	46.94	- - -	53.06	- - -	37.91	62.09
330	Medicine Bow	2	NE 35	21N	79W	1,701	693	- -	- -	289	68	Tr	1,405	30.13	- - -	- - -	5.18	1.92	- - -	23.03	23.56	- - -	76.44	- - -	27.03	72.97
331	Medicine Bow	2	NE 35	21N	79W	1,839	752	- -	- -	264	41	39	1,470	32.72	- - -	- - -	5.49	1.16	1.97	24.10	20.32	- - -	79.68	- - -	17.43	82.57
332	Medicine Bow	2	NW 35	21N	79W	1,672	683	- -	- -	259	52	24	1,370	29.70	- - -	- - -	4.97	1.47	0.80	22.46	21.70	- - -	78.30	- - -	22.89	77.11
333	Medicine Bow	2	NW 36	21N	79W	1,789	665	- -	- -	477	157	24	830	28.76	- - -	- - -	9.93	4.43	0.80	13.60	49.92	- - -	50.08	- - -	30.83	69.17
334	Medicine Bow	2	NW 36	21N	79W	1,736	683	- -	- -	376	146	54	970	29.95	- - -	- - -	7.83	4.12	1.80	15.90	40.30	- - -	59.70	- - -	34.47	65.53
335	Medicine Bow	2	NW 36	21N	79W	1,713	669	- -	- -	422	167	54	825	28.82	- - -	- - -	8.79	4.71	1.80	13.52	46.84	- - -	53.16	- - -	34.89	65.11
336	Medicine Bow	2	NW 36	21N	79W	1,728	701	- -	- -	242	72	59	1,310	30.50	- - -	- - -	5.03	2.03	1.97	21.47	23.14	- - -	76.86	- - -	28.76	71.24
337	Medicine Bow	3	NW 36	21N	79W	1,814	726	- -	- -	320	130	50	1,195	31.60	- - -	- - -	6.67	3.67	1.67	19.59	32.72	- - -	67.28	- - -	35.49	64.51
338	Medicine Bow	3	NW 36	21N	79W	1,808	732	- -	- -	258	156	50	1,245	31.85	- - -	- - -	5.37	4.40	1.67	20.41	30.68	- - -	69.32	- - -	45.05	54.95
339	Rock Creek	1	NE 34	20N	78W	2,311	920	- -	- -	392	286	101	1,245	40.02	- - -	- - -	8.17	8.07	3.37	20.41	40.58	- - -	59.42	- - -	49.69	50.31

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
														LARAMIE BASIN (Continued from Page 1)											
340	Rock Creek	3	NE 34	20N	78W	2,475	963	- -	- -	412	695	Tr	905	41.88	- - -	- - -	8.58	18.47	- - -	14.83	64.58	- - -	35.42	- - -	68.29	31.71
341	Rock Creek	1	NE 34	20N	78W	3,075	1,180	- -	- -	637	756	138	740	51.32	- - -	- - -	13.26	21.33	4.60	12.13	67.40	- - -	32.60	- - -	61.67	38.33
342	Rock Creek	5	NW 35	20N	78W	2,449	978	- -	- -	397	308	210	1,140	42.65	- - -	- - -	8.27	8.69	7.00	18.69	39.76	- - -	60.24	- - -	51.24	48.76
343	Rock Creek	6	NW 35	20N	78W	1,840	744	- -	- -	272	152	210	940	32.36	- - -	- - -	5.66	4.29	7.00	15.41	30.76	- - -	69.24	- - -	43.14	56.86
344	Rock Creek	8	SW 35	20N	78W	2,274	918	- -	- -	319	227	252	1,120	40.06	- - -	- - -	6.65	6.40	8.64	18.36	32.58	- - -	67.42	- - -	49.05	50.95
345	Rock Creek	6	SW 35	20N	78W	1,998	811	- -	- -	299	182	66	1,370	35.30	- - -	- - -	6.23	5.13	2.20	22.46	30.14	- - -	69.86	- - -	48.22	51.78
346	Rock Creek	9	SW 35	20N	78W	2,075	636	- -	- -	314	194	180	1,120	36.37	- - -	- - -	6.54	5.47	6.00	18.36	33.02	- - -	66.98	- - -	45.54	54.46
347	Rock Creek	10	SW 35	20N	78W	2,561	1,031	- -	- -	338	373	175	1,310	44.86	- - -	- - -	7.04	10.52	5.83	21.47	59.14	- - -	60.86	- - -	59.52	40.08
348	Rock Creek	10	SW 35	20N	78W	2,306	916	- -	- -	376	339	325	675	39.84	- - -	- - -	7.83	10.12	10.83	11.06	45.06	- - -	54.94	- - -	56.37	43.63
349	Rock Creek	10	SW 35	20N	78W	2,279	924	- -	- -	297	245	120	1,410	40.20	- - -	- - -	6.18	6.91	4.00	23.11	32.56	- - -	67.44	- - -	52.78	47.22
350	Rock Creek	1	NW 11	19N	78W	1,921	778	- -	- -	263	192	155	1,085	33.84	- - -	- - -	5.47	5.42	5.17	17.78	32.18	- - -	67.82	- - -	49.77	50.23
														POISON SPIDER AREA											
351	Bolton Creek	1	NE 9	29N	81W	1,774	664	- -	- -	595	140	6	750	28.83	- - -	- - -	12.39	3.95	0.20	12.29	56.68	- - -	43.32	- - -	24.18	75.82
352	Spindletop	3	NW 5	29N	81W	2,126	790	- -	- -	762	127	- -	910	34.35	- - -	- - -	15.86	3.58	- - -	14.91	56.60	- - -	43.40	- - -	18.41	81.59
353	Poison Spider	6	12	33N	83W	1,601	670	6	7	32	24	223	1,196	29.18	0.30	0.58	0.73	0.70	7.42	21.21	4.74	- - -	92.28	2.98	48.54	51.46
354	Poison Spider	11	12	33N	83W	1,474	580	6	18	66	25	191	1,293	26.27	0.30	1.48	1.37	0.71	6.36	19.61	7.36	- - -	86.28	6.36	43.97	66.03
355	Poison Spider	2	13	33N	83W	1,519	700	6	14	99	85	159	1,464	30.47	0.30	1.15	2.07	0.71	5.29	23.85	8.74	- - -	86.72	4.54	25.86	74.14
356	Poison Spider	1	7	33N	82W	1,859	780	- -	- -	80	215	192	1,208	33.87	- - -	- - -	1.66	6.02	6.39	19.80	22.66	- - -	77.34	- - -	78.28	21.72
357	Poison Spider	10	12	33N	82W	2,135	873	11	- -	135	284	127	1,435	38.01	0.55	- - -	2.81	8.02	4.23	23.50	28.20	- - -	70.38	1.42	74.11	25.89
358	Poison Spider	3	18	33N	82W	2,069	824	- -	- -	374	207	133	1,080	35.84	- - -	- - -	7.88	5.83	4.43	17.70	38.24	- - -	61.76	- - -	42.47	57.53
359	South Casper Creek	1A	NW 2	33N	83W	2,081	1,096	44	Tr	528	775	- -	1,040	47.71	2.20	- - -	10.99	21.87	- - -	17.95	65.80	- - -	29.80	4.40	66.56	33.44
														POWDER RIVER BASIN											
360	Tisdale	1	SW 27	42N	81W	15,568	5,035	560	157	2,375	7,409	- -	68	219.12	27.39	12.91	49.40	208.93	- - -	1.09	84.46	15.12	- - -	0.42	80.92	19.08
361	Salt Creek(2nd Sand)	18d	SW 23	40N	79W	9,483	3,827	24	12	90	4,850	Tr	1,220	166.49	1.20	0.99	1.87	136.81	- - -	20.00	87.40	- - -	11.30	1.30	91.79	8.21
362	Salt Creek(2nd Sand)	6	SW 24	40N	79W	7,517	2,988	20	10	Tr	3,550	Tr	1,930	129.95	1.00	0.82	- - -	100.14	- - -	31.63	76.00	- - -	22.60	1.40	100.00	- - -
363	*Salt Creek(2nd Sand)	218d	SW 25	40N	79W	9,639	3,720	44	15	568	4,500	- -	1,610	161.72	2.20	1.23	11.83	126.94	- - -	26.39	84.00	- - -	13.20	2.80	90.95	9.05
364	Salt Creek(3rd Sand)	318d	NW 35	40N	79W	13,200	4,511	260	16	3,905	4,125	- -	780	196.14	12.99	1.32	81.30	116.36	- - -	12.78	93.20	0.72	- - -	6.08	58.91	41.09
365	Salt Creek(3rd Sand)	38d	SW 35	40N	79W	14,146	4,259	264	56	5,317	3,950	Tr	610	185.16	13.18	4.61	110.70	82.24	- - -	10.00	91.32	3.88	- - -	4.80	42.65	57.35
366	*Salt Creek(3rd Sand)	58d	SW 35	40N	79W	11,981	4,009	334	59	2,862	4,568	- -	710	174.38	16.67	4.85	55.42	128.85	- - -	11.63	89.02	5.04	- - -	5.94	69.92	30.08
367	Salt Creek(3rd Sand)	168d	SW 35	40N	79W	11,327	3,711	400	52	2,534	4,200	- -	875	161.33	19.97	4.28	52.76	118.47	- - -	14.34	87.00	5.20	- - -	7.80	69.14	30.81
368	Big Muddy	60	9	33N	76W	4,044	1,492	- -	- -	1,330	686	37	1,015	64.92	- - -	- - -	27.69	19.36	1.23	16.64	72.48	- - -	27.52	- - -	41.15	58.85
369	Lance Creek	3	NW 33	36N	65W	7,275	2,245	185	Tr	4,346	247	- -	575	97.65	9.23	- - -	90.49	6.97	- - -	9.42	91.18	- - -	0.18	8.64	7.15	92.85
370	Lance Creek	1	NW 6	35N	65W	5,647	1,867	85	Tr	3,039	894	- -	330	81.19	4.24	- - -	63.27	16.75	- - -	5.41	93.66	- - -	1.38	4.96	20.93	79.07
371	Lance Creek	2	SW 6	35N	65W	9,236	2,753	265	Tr	5,879	145	- -	395	119.75	13.22	- - -	122.40	4.09	- - -	6.48	90.06	5.08	- - -	4.86	3.25	96.75
372	Lance Creek	E2	SE 6	35N	65W	5,955	1,892	101	26	3,138	473	Tr	660	82.31	5.04	2.14	65.33	13.34	- - -	10.82	87.90	- - -	4.08	8.02	16.95	83.05

* Hydrogen sulphide present.

fields where a deep-seated Cloverly sandstone yields a sulphate-saline water. This departure from the normal is ascribed to purely local sand conditions. The concentration of the water varies from an average of 3,000 parts per million in the western part to about 800 parts per million in the eastern part of the basin.

In the northeastern part of the Powder River Basin, dilute, potable, sulphate-saline water is found, the average Lakota water having a concentration of about 800 parts per million. Local sand conditions cause some variation in concentration, but 1,200 parts per million is the maximum so far found in this area. The "Dakota group" sands lie comparatively close to the surface in this area, and the sands are fed by surface water from the west slope of the Black Hills uplift.

SUNDANCE FORMATION WATERS

The marine Sundance formation, of Upper Jurassic age, underlies the Morrison formation and overlies the Chugwater formation of Permian and Triassic age. It consists mostly of gray sandstone, shaly and calcareous sand, and ranges from 60 feet to 1,075 feet in thickness. The sandstones are ordinarily relatively soft, porous and permeable. The formation is comparatively uniform in distribution, and since 1935 has been one of the best oil-producing zones in the state, particularly in the Medicine Bow and Lance Creek fields. In the Laramie Basin it has two prominent sandstone beds, whereas in the Salt Creek field three are present.

Two types of Sundance water are found in Wyoming: (1) a water of high primary salinity with a concentration varying from 4,000 to 15,000 parts per million, such as occurs at Baxter Basin and in the fields of the Powder River Basin; and (2) a water averaging 2,000 parts per million such as is present in the fields of the Laramie Basin and the Poison Spider area. Hydrogen sulphide occurs in some Sundance waters of the Powder River Basin, but is not present in those waters in the Laramie Basin or Poison Spider area and, except for concentration, their counterpart can be found in the Cloverly waters.

In general, Sundance waters are solutions of sodium salts with small amounts of calcium and magnesium. Sulphate ranges from a trace to 95 per cent of the salinity.

SWEETWATER BASIN

Baxter Basin fields.—The so-called Sundance is the lowest formation drilled on the Rock Springs uplift. In North Baxter Basin the so-called Sundance sandstone produces commercial quantities of gas, with a showing of oil in one well. The same bed, although about 1,200 feet structurally higher, is barren in South Baxter Basin. This sand

is fine-grained, white to buff, and cross-bedded. More than 200 feet of the sand has been drilled at North Baxter Basin. The so-called Sundance has a total thickness of 1,075 feet and lies at an average depth of 3,500 feet below the surface.

The Selegna well on Sec. 11, T. 20 N., R. 104 W., is the lowest Sundance well structurally that has been drilled at Baxter Basin. The Sundance was first logged at a depth of 4,505 feet, and a water sample obtained at 4,540 feet with a Halliburton tester. This water is represented by analysis 300. At 5,014 feet the sample represented by analysis 301 was taken.

The well in Sec. 2, T. 19 N., R. 104 W., is on the downthrown side of a fault block and is the only well that showed oil in the Sundance formation. It originally produced about 4 barrels of oil a day but soon declined to about 1½ barrels a day with an influx of water. This water approaches the Frontier water of this field in concentration, but is distinguished from it by its high sulphate content. It is unquestionably Sundance water, although abnormal. Its much higher concentration is caused principally by increased sodium chloride, which, in turn, is ascribed to stagnancy caused by association with oil. This condition is present elsewhere, notably in the First Wall Creek sand at Salt Creek, where the water in the oil-producing area contains ten times as much chloride as the same water elsewhere in the field.

The localization of Sundance waters at Baxter Basin is well illustrated by analyses from well No. 1, Sec. 18, T. 19 N., R. 103 W., where the top of the formation was logged at a depth of 3,523 feet. Analyses 305 and 306 were taken from what is locally called "Upper Sundance," a shaly sand about 200 feet thick. The well then penetrated black shale breaks into a second Sundance sand, where analyses 307 and 308 were taken. At depths from 3,980 to 3,993 feet and 4,044 to 4,090 feet, the well went through red shale breaks into a third sand from which analyses 309–311 were taken.

The analyses in Table V and Figure 15 show that the "Upper Sundance" water is 75 per cent saline and the second sand water only 49 per cent saline. The third sand water has a salinity of 64 per cent but may be distinguished from the other two by its lower concentration and by its hydrogen sulphide content.

Because of the chemical differences just stated, the water represented by analysis 304 is called "Upper Sundance" water, which it undoubtedly is as it lies immediately below the gas in the same sand. Analysis 301 from the Selegna well is third sand water and in concentration is correlated with water from that sand in the well in Sec. 18, T. 19 N., R. 103 W., although hydrogen sulphide is not

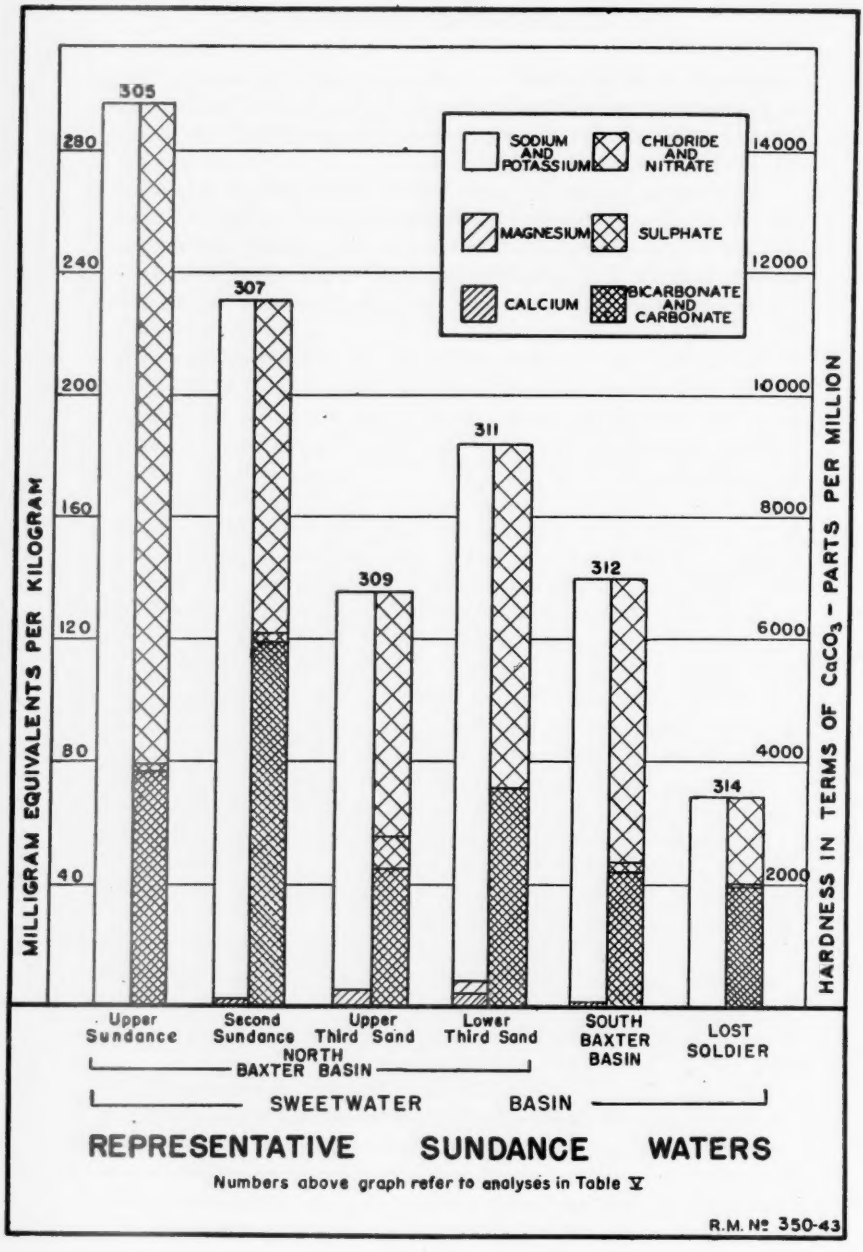

MILLIGRAM EQUIVALENTS PER KILOGRAM
280
240
200
160
120
80
40
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
14000
12000
10000
8000
6000
4000
2000
SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
305
307
309
311
312
314
Upper Sundance
Second Sundance
Upper Third Sand
Lower Third Sand
SOUTH BAXTER BASIN
LOST SOLDIER
NORTH BAXTER BASIN
SWEETWATER BASIN
REPRESENTATIVE SUNDANCE WATERS
Numbers above graph refer to analyses in Table V
R.M. № 350-43

FIG. 15

present. Analysis 300 from the "Upper Sundance" in the same well is abnormal.

Although Sundance waters can be distinguished from Frontier waters at Baxter Basin by the presence of sulphate in the former, no definite rules can be given for differentiating Sundance waters from Dakota (?) sandstone waters. Perhaps fault planes have permitted the migration of water from one zone to the other, so that distinct characteristics usually found between waters of different zones are absent.

Lost Soldier field.—In the Lost Soldier field the top of the producing sand of the Sundance formation lies at an average depth of 2,000 feet below the surface and is about 300 feet thick. The sand is gray, porous, has some shale breaks, and locally is "tight" because of calcium carbonate cement. Although it is an important oil-producing zone at Lost Soldier, this sand has a smaller productive area than the sands of the "Dakota group."

The well represented by analysis 314 was low structurally and produced only water. The other wells in Table V were high structurally and produce both oil and water.

The Sundance water at Lost Soldier is the most dilute formation water found there, having one-third the concentration of Frontier water, one-half the concentration of Muddy sand water, and four-fifths the concentration of Cloverly waters. It is essentially a solution of sodium chloride and sodium bicarbonate in the proportions of 2 to 3 and has its counterpart in the upper Cloverly water.

Sundance water at Lost Soldier can be distinguished from Frontier water by its lower concentration, and from waters of the "Dakota group" by its lower concentration and absence of the sulphate radicle present in the latter.

LARAMIE BASIN

Allen Lake gas field.—The top of the gas-producing sand in the Sundance formation in the Allen Lake field is about 2,000 feet deep and is 250 feet thick. It consists of gray sand, with some hard, tightly cemented portions and a 20-foot shale break near the bottom. This break is apparently present throughout the Laramie Basin.

The Sundance water in this field resembles equivalent waters elsewhere in the basin, differing only in its much lower sulphate content and a somewhat higher chloride content.

Medicine Bow oil field.—Two Sundance sands are present in the Medicine Bow structure, both containing gas, oil, and water. The first sand, which some include in the Morrison formation, is 50 feet thick, and is underlain by a shale and limestone unit approximately

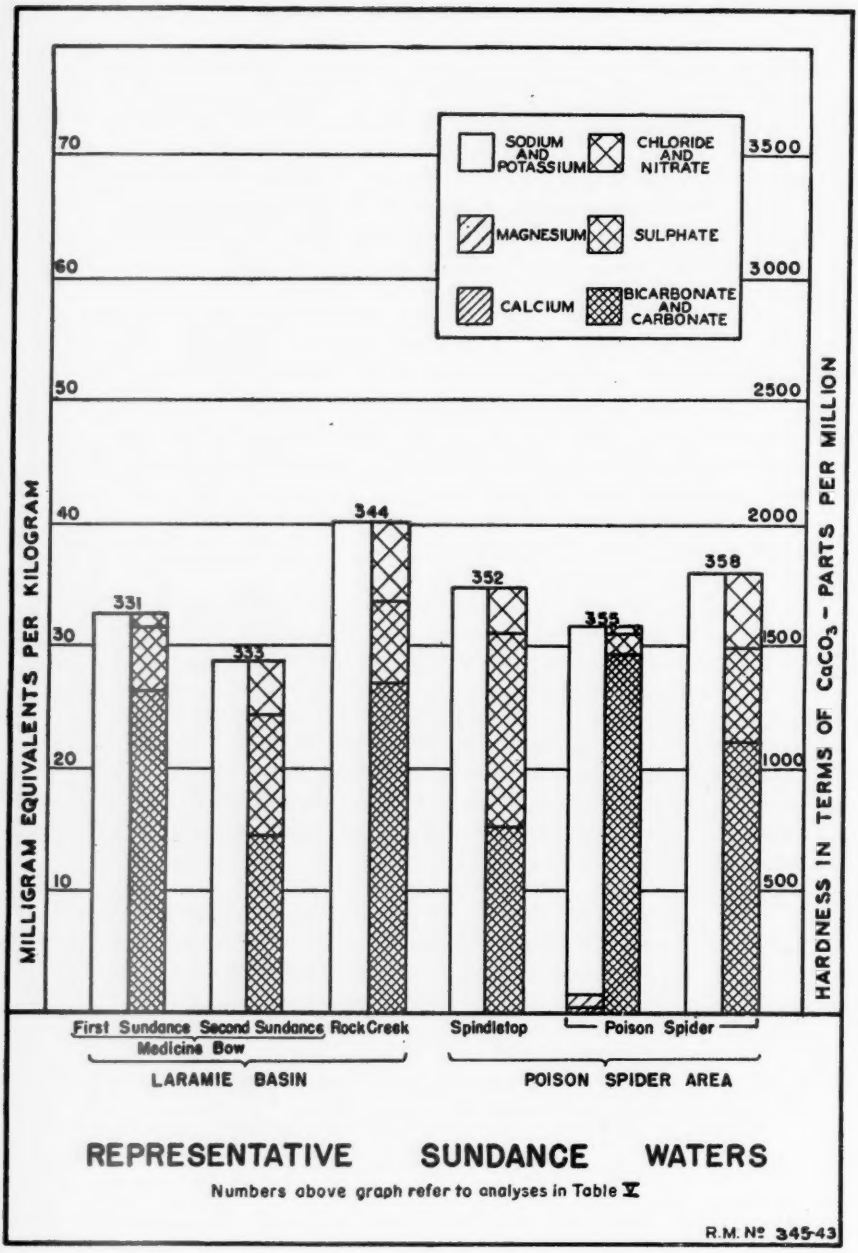

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
70
60
50
40
30
20
10
3500
3000
2500
2000
1500
1000
500
331
333
344
352
355
358
First Sundance
Second Sundance
Rock Creek
Medicine Bow
LARAMIE BASIN
Spindletop
Poison Spider
POISON SPIDER AREA
REPRESENTATIVE SUNDANCE WATERS
Numbers above graph refer to analyses in Table V
R.M. Nº 345-43

FIG. 16

50 feet thick. The second sand is about 100 feet thick and has a shale break at its base similar to that in the Allen Lake field. On the crest of the structure the top of the first sand occurs at a depth of about 5,100 feet, and on the flanks at about 5,600 feet.

Primary alkalinity dominates the water, which is essentially a solution of sodium salts. Sulphate averages 65 per cent of the salinity. Attempts have been made to distinguish between first and second sand waters, but a precise correlation is not yet possible. The two sands have the same source water with the same freedom of flow, and it may be that they are simply tongues of the main sand body.

Analyses 331 and 332 are of first sand water as are analyses 336–338. These analyses show that criteria for differentiating the two waters might be based on increased alkalinity. Thus a tentative correlation can be made by postulating that those waters whose bicarbonate is more than 1,100 parts per million are first sand waters, and those whose bicarbonate is less than 1,100 parts per million are either second sand waters or a mixture of first and second sand waters. More analyses of known first sand waters are necessary before this tentative method of correlation can be confirmed.

The Tensleep water at Medicine Bow is more concentrated and contains notable quantities of calcium and magnesium which differentiates it from the more dilute, soft Sundance water.

Rock Creek oil field.—As in the Medicine Bow field, two sandstones are present in the Sundance formation in the Rock Creek field. The top of the first, or upper, sand lies 3,100–3,500 feet below the surface, averages 40 feet in thickness, and contains both oil and water. The second, or lower, sand averages 135 feet in thickness and contains only water. All oil wells produce from the first sand, although several penetrated the second.

The analyses listed in Table V are from the first sand. The water is similar to first sand water at Medicine Bow, though slightly more concentrated and with a slightly higher average chloride content.

This water is far more dilute than the Cloverly water in this field, and contains appreciable quantities of sulphate.

POISON SPIDER AREA

Bolton Creek field.—Three wells produce oil from the Sundance formation in the Bolton Creek field, and the formation was logged at 1,149–1,390 feet. The producing horizon is a light gray sand, free of shale, and somewhat cemented with calcium carbonate. The water is similar in concentration and characteristics to Sundance water in the Laramie Basin, being essentially a solution of sodium salts. It differs from Dakota (?) water in this field by its greater concentration.

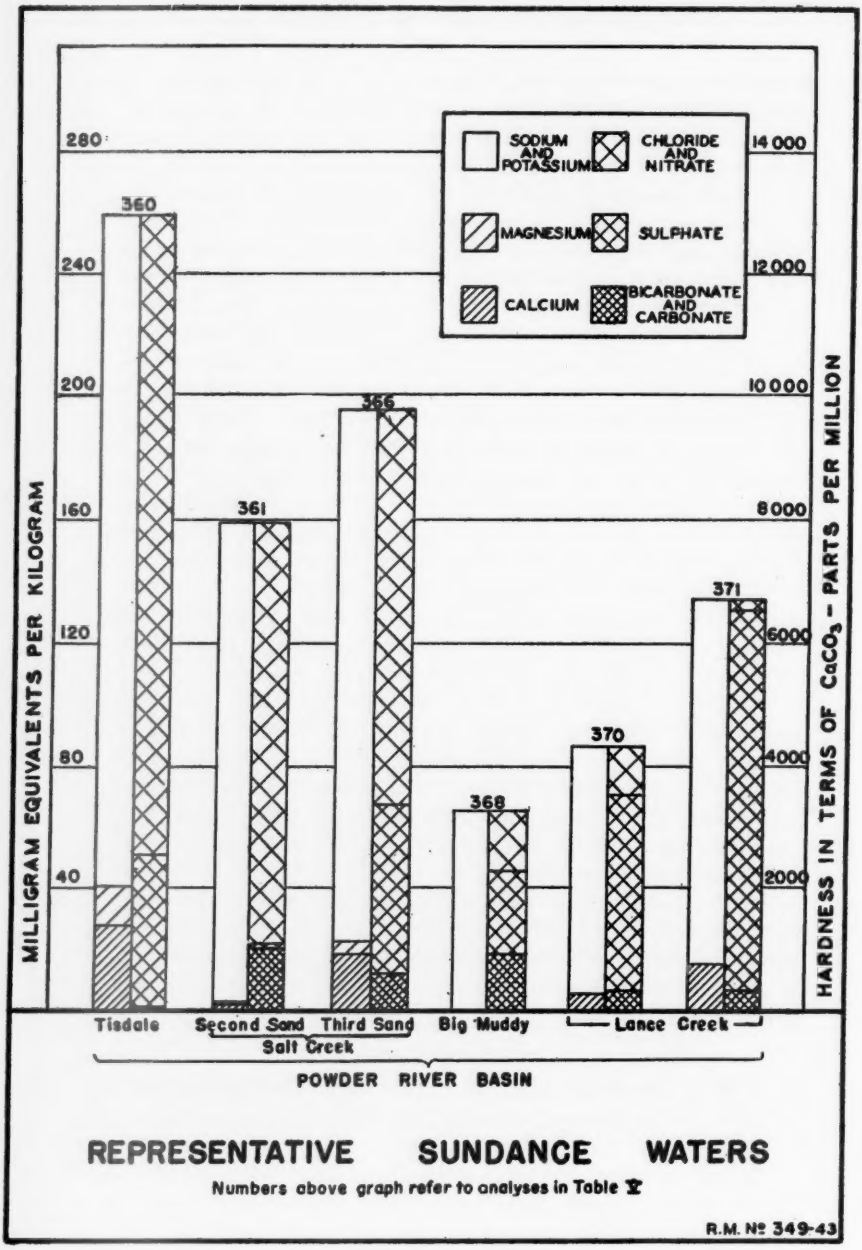

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
280
240
200
160
120
80
40
14 000
12 000
10 000
8000
6000
4000
2000
360
361
366
368
370
371
Tisdale
Second Sand
Third Sand
Salt Creek
Big Muddy
Lance Creek
POWDER RIVER BASIN
REPRESENTATIVE SUNDANCE WATERS
Numbers above graph refer to analyses in Table X
R.M. № 349-43

FIG. 17

Spindletop dome.—In the Spindletop field a gray Sundance sandstone about 80 feet thick lies about 1,100 feet below the surface and produces most of the oil, as at Bolton Creek. The water from this sandstone is almost like that at Bolton Creek, and may be differentiated from Dakota (?) sandstone water by its greater concentration and increased chloride radicle.

Poison Spider field.—The oil-producing sands in the Poison Spider field are in the Sundance and the top of the Chugwater formations. The sandstone in the Sundance is about 60 feet thick and lies about 1,200 feet deep on the crest of the structure and 1,500 feet deep on the flanks.

On the west side of the field a low chloride water, indicating a free water movement in the sand, occurs in the Sundance, whereas on the east side of the field a higher chloride water is present. Local sand conditions may cause this variation, or it is possible that the higher chloride water may be coming from the top of the Chugwater, or the Sundance-Chugwater contact. In any event the Sundance waters can be distinguished from the Dakota (?) sandstone water by the higher concentration of the former.

South Casper Creek structure.—About 40 feet of light gray Sundance sandstone is logged at a depth of 1,325–1,360 feet in the South Casper Creek field. Gas was originally produced from this sand, but now it contains only water. Showings of oil were found on the flanks of the structure, but no commercial wells were developed.

This water is more saline than most Sundance waters in this area, but in all other respects is normal.

POWDER RIVER BASIN

Tisdale structure.—In the well from which analysis 360 was obtained the Sundance formation was logged at 1,235–1,390 feet and only showings of oil and gas were found.

In the lower Sundance sandstone the well yielded 2,000 barrels of water daily. This water, though more saline, has been correlated with the third Sundance sand water in the Salt Creek field and shows that a semi-stagnant water condition exists in the sand in the Tisdale structure despite the fact that the sand crops out a few miles north.

Unlike Sundance waters elsewhere, those in the Powder River Basin are concentrated waters in which calcium sulphate is prominent. Magnesium sulphate is also prominent in the Sundance water from this structure.

The artesian Tensleep water is the only other water sampled at Tisdale and can be distinguished from Sundance water by its lower concentration, which ranges from 2,500 to 3,000 parts per million.

Salt Creek oil field.—Three distinct Sundance sands are present in the Salt Creek oil field. The top of the first sand is logged at an average depth of 2,400 feet in the oil-producing third Sundance area, where it is usually non-productive of oil or gas. The lenticular second sand produces some oil but the wells did not flow because of low permeability. The permeable and porous third sand is the important oil-producing zone in the Sundance, and the wells flowed.

The upper Sundance waters (both first and second sands) are essentially solutions of sodium salts with little or no calcium and magnesium. Sulphate occurs in minor amounts, although analysis 383 shows more than 500 parts per million. The bicarbonate radicle is 1,200 parts per million or better, averaging twice that of the third sand water, and hydrogen sulphide is rarely present.

In contrast, the third Sundance water is more concentrated, carries large quantities of calcium sulphate, has a lower bicarbonate content, and has some hydrogen sulphide. The apparent inconsistency of analysis 363, both as to sulphate content and the presence of hydrogen sulphide, is caused by contamination with third sand water. A study of the log shows that this well was drilled into the third sand when the first sand was producing water. Some third sand contamination was, therefore, present but insufficient to invalidate the results.

The third Sundance water is the first subsurface water in the Salt Creek field to show appreciable amounts of calcium and magnesium, and can thereby be distinguished from all upper waters. It differs from the Tensleep water by its much greater concentration and its high chloride content.

The upper Sundance waters can be differentiated from younger formation waters by their concentration and the chloride-bicarbonate ratio as compared with the Second Wall Creek waters, their nearest counterpart.

Big Muddy oil field.—The Sundance formation produces no oil in the Big Muddy field, one well drilled to it having flowed 2,000 barrels of water a day at depths of 4,865–4,910 feet. The water differs from the Shannon and Frontier waters by the presence of sulphate, and from the basal Cloverly water by its greater concentration and higher salinity.

Lance Creek oil field.—The Sundance is one of the principal oil-producing formations in the Lance Creek field and is logged at depths of 3,800–4,000 feet. It consists of about 100 feet of calcareous green shale, 100 feet of red and gray sandstone and sandy shale productive of black oil near the crest of the structure, 50 feet of dark green to black calcareous shale, and 100 feet of gray to buff sandstone which carries oil. Its average thickness is about 350 feet.

Primary salinity dominates Sundance water and, in addition, there is 5–8 per cent secondary alkalinity. It is noticeable that the chloride content of the Sundance waters in the Powder River Basin is at its maximum at Tisdale to the north and west, and reaches its minimum value at Lance Creek, in the southeastern part of the basin.

The high sulphate content of the Sundance water at Lance Creek distinguishes it from the sulphate-free Fall River water there, and its concentration, ranging from 5,000 to 9,000 parts per million, distinguishes it from Minnelusa water—both Converse and Leo water—which does not exceed 3,000 parts per million.[6]

SUMMARY

Sundance waters are usually solutions of sodium salts somewhat similar, except in concentration, to younger formation waters previously discussed. Hydrogen sulphide commonly occurs in water from the lower sandstone member of the formation and nickel has been reported in the lower Sundance water of the Salt Creek oil field.

Sweetwater Basin, which includes the highly faulted Baxter Basin fields, contains the most erratic Sundance waters in the state. A saline water, ranging in concentration from 4,000 to 50,000 parts per million and containing varying amounts of calcium and magnesium sulphate, occurs there. The Lost Soldier field on the northeast edge of the basin produces a sodium chloride-bicarbonate type of water.

Throughout Laramie Basin and the Poison Spider area a remarkable uniformity of concentration and chemical characteristics appears in Sundance water. The concentration ranges from 1,500 to 2,500 parts per million and calcium and magnesium are either absent or present only in traces.

A restricted circulation of Sundance water is indicated in the Powder River Basin by a concentration ranging from 4,000 to 15,000 parts per million. Calcium and magnesium occur there in notable quantities and salinity occupies from 70 to 90 per cent of the chemical system.

EMBAR FORMATION WATERS

The Embar formation of Permian and Triassic age underlies the Triassic redbeds and consists of light-colored limestone, chert, varicolored sandstone, sandy limestone, and red shale, ranging from 60 to 400 feet in thickness. The porous members produce black oil in some areas, particularly in the Big Horn Basin.

The Tensleep sandstone lies just below the Embar and the divid-

[6] "Since this paragraph was written Leo sand water has been analyzed with a concentration of 5,000 parts per million; its typical Minnelusa characteristics, however, easily distinguish it from Sundance waters.

TABLE VI

Embar Formation Waters

Number	Location					Parts per million								Milligram equivalents							Properties of reaction in per cent					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
														BIG HORN BASIN												
373	Byron	1	NE 36	56N	97W	3,556	1,174	41	--	1,869	305	--	340	51.05	2.05	---	38.92	8.60	---	5.58	89.50	---	6.84	3.86	18.10	81.90
374	Oregon Basin	1	NE 9	51N	100W	6,863	1,680	374	200	3,472	400	--	1,500	73.03	18.67	16.45	72.29	11.28	---	24.58	67.60	9.84	---	22.76	13.27	86.73
375	Oregon Basin	2	SW 9	51N	100W	6,047	1,323	498	170	2,999	350	--	1,520	57.55	24.86	13.98	61.61	9.87	---	24.91	69.80	14.40	---	25.80	13.75	86.25
376	Oregon Basin	4	NW 8	51N	100W	5,902	1,392	420	168	2,746	650	--	1,075	60.50	20.96	11.62	57.13	18.33	---	17.62	85.00	16.00	---	19.00	24.20	75.80
377	Oregon Basin	6	NE 7	51N	100W	5,486	1,433	546	164	3,136	450	--	1,535	62.30	27.35	13.48	65.29	12.69	---	25.16	60.40	15.20	---	24.40	16.06	83.94
378	*Oregon Basin	6	NE 7	51N	100W	6,547	1,439	564	166	3,194	395	--	1,685	62.61	28.15	13.85	65.66	11.14	---	27.61	69.96	13.60	---	25.84	14.52	85.48
379	Oregon Basin	2	NE 36	51N	101W	9,072	2,189	528	222	3,805	1,700	--	1,075	95.18	31.35	18.26	79.22	47.95	---	17.62	66.00	21.80	---	12.20	37.99	62.41
380	*Hamilton Dome	1	NW 14	44N	98W	7,081	1,828	530	94	2,638	1,477	--	1,045	79.52	26.46	7.73	54.92	41.66	---	17.13	69.94	15.00	---	15.06	43.14	56.86
381	Hamilton Dome	3	NW 14	44N	98W	10,567	3,620	56	32	4,239	2,500	--	245	157.37	2.79	2.63	88.26	70.52	---	4.01	95.20	1.20	---	1.60	44.40	55.60
382	Hamilton Dome	20	NW 14	44N	98W	15,787	5,166	320	82	5,787	3,925	--	990	224.72	15.97	6.74	120.48	110.72	---	16.23	90.82	2.62	---	6.56	47.90	52.10
383	Hamilton Dome	20	NW 14	44N	98W	12,992	3,867	273	90	4,992	3,000	--	550	168.22	13.62	7.40	95.61	84.62	---	9.01	88.90	6.34	---	4.76	46.95	53.05
384	Hamilton Dome	20	NW 14	44N	98W	11,588	3,673	338	75	4,199	2,970	--	760	159.78	16.87	6.17	86.59	83.78	---	12.45	87.40	5.78	---	6.82	49.17	50.83
385	Hamilton Dome	1	SW 14	44N	98W	10,543	3,294	326	81	3,851	2,667	--	660	143.30	16.27	6.66	80.18	75.24	---	10.81	86.20	7.30	---	6.50	48.41	51.99
386	Keogh Dome	1	NE 12	44N	97W	2,426	640	57	79	1,356	173	--	245	27.78	2.85	6.50	28.23	4.88	---	4.02	74.82	14.36	---	10.82	14.74	85.26
387	*Keogh Dome	1	NE 12	44N	97W	4,884	1,071	489	105	1,967	993	--	1,340	46.61	24.41	8.63	40.96	16.72	---	21.97	58.52	13.90	---	27.58	28.99	71.01
388	*Keogh Dome	1	NE 12	44N	97W	4,314	932	457	89	1,694	515	--	1,275	40.55	22.82	7.32	35.27	14.52	---	20.90	57.36	13.08	---	29.56	29.17	70.83
389	*Keogh Dome	1	NE 12	44N	97W	4,277	866	505	85	1,752	437	--	1,285	37.65	25.21	6.99	36.47	12.32	---	21.06	53.90	15.96	---	30.14	25.26	74.74
390	*Keogh Dome	1	NE 12	44N	97W	4,544	1,116	358	90	1,854	452	--	1,370	48.54	17.87	7.40	38.60	12.75	---	22.46	65.76	3.82	---	30.42	24.84	75.16
391	Keogh Dome	2	NW 7	44N	96W	3,303	905	173	65	1,376	340	--	915	39.26	8.63	5.35	28.65	9.59	---	15.00	71.82	---	1.92	26.26	25.07	74.93
392	Thermopolis	1	24	42N	95W	965	45	182	76	355	66	--	490	1.96	9.09	6.25	7.40	1.86	---	8.04	11.34	38.18	---	46.46	20.08	79.92
393	*East Term Springs	9	NE 36	43N	94W	2,995	263	548	135	1,376	235	--	890	11.41	27.36	11.10	28.65	6.63	---	14.59	22.82	47.86	---	29.26	18.80	81.20
394	*Black Mountain	1	NW 35	43N	91W	4,125	1,443	--	--	2,113	32	50	990	62.79	---	---	43.99	0.90	1.67	16.23	71.48	---	28.52	---	1.99	98.01
395	**Black Mountain	2	NW 35	43N	91W	3,745	428	673	99	1,935	35	34	1,097	18.60	33.50	8.12	40.25	0.98	1.13	18.00	30.90	37.50	---	31.60	2.34	97.66
396	**Black Mountain	2	NW 35	43N	91W	3,802	427	582	154	2,176	78	--	781	18.55	29.10	12.60	45.26	2.20	---	12.83	29.80	45.60	---	24.60	3.98	96.12
														WIND RIVER BASIN												
397	*Lander	2	SE 30	34N	99W	492	93	99	27	81	43	--	385	4.05	2.94	2.22	1.69	1.21	---	6.31	31.48	---	12.50	56.02	41.74	58.26
398	*Lander	5	4	33N	99W	740	117	109	28	256	38	--	390	5.06	5.44	2.30	5.33	1.07	---	6.40	39.54	10.46	---	50.00	16.72	83.28
399	Derby Dome	1	NW 4	31N	98W	673	185	50	--	312	25	--	205	8.07	2.50	---	6.50	0.71	---	3.36	68.40	---	7.90	23.70	9.98	90.02
400	Derby Dome	2	NW 4	31N	98W	502	140	42	--	192	20	--	220	6.07	2.10	---	4.00	0.56	---	3.61	55.80	---	18.50	25.70	12.37	87.63
401	*Derby Dome	5	NW 4	31N	98W	540	193	56	--	328	30	--	230	8.37	2.80	---	6.83	0.56	---	3.77	66.20	---	8.80	25.00	7.58	92.42
402	Derby Dome	2	SE 29	32N	98W	1,745	355	132	45	1,072	40	--	205	15.52	6.59	3.70	22.32	1.13	---	2.36	60.20	30.74	---	9.06	4.77	95.23
403	*Derby Dome	2	SE 29	32N	98W	2,001	373	220	43	1,178	12	--	355	16.16	10.98	3.54	24.52	0.34	---	5.82	52.68	28.34	---	18.98	1.36	98.64
														SHERIDAN BASIN												
404	*Sheep Creek	2		28N	92W	5,853	1,198	503	195	2,963	335	--	1,340	51.97	25.11	16.03	61.69	9.45	---	21.97	55.82	20.58	---	23.60	13.28	86.72

* Analyses courtesy Midwest Refining Company.
**Hydrogen sulphide present.

ing line is rather indefinite. Oil, where present in the Embar, ordinarily occurs in the upper part, and water is almost everywhere associated with the oil.

Typical Embar water samples have been obtained only in the Big Horn Basin, in the Lander area of the Wind River Basin, and from one well on the Sheep Creek structure in the Sweetwater Basin. Elsewhere the Embar is ordinarily of no importance from an oil and gas standpoint. The water is of the primary saline type with notable percentages of secondary salinity and secondary alkalinity. In the southern part of the Big Horn Basin secondary salinity is the dominant characteristic, and primary alkalinity is found in some of the samples from the Lander area. From 50 to 90 per cent of the salinity is due to the sulphate radicle and the water is characterized by its preponderance of the alkaline earths and the sulphate radicle. Hydrogen sulphide, though not reported in all the analyses, is ordinarily found in Embar waters.

Acidization of the Embar formation in several fields has resulted in changes in the concentration and other characteristics of the contained water. In general, the concentration is increased from 25 to 100 per cent, the additional solids showing up in the water as the chlorides and bicarbonates of calcium and magnesium. In correlating water samples from limestone it is important to know, therefore, whether acidization has taken place, and to take into consideration any alterations the water may thus have undergone.

BIG HORN BASIN

Byron field.—The well from which analysis 373 was obtained in the Byron field was drilled into the Tensleep sandstone with the Embar formation exposed in the hole, and the well swabbed from 4 to 40 per cent water. The top of the Embar was logged at 5,340 feet, its bottom at about 5,405 feet.

The sample was somewhat diluted by Tensleep water, but the percentage was too small to affect seriously the characteristics of the Embar water. This is the deepest Embar water sampled in the Big Horn Basin and differs from other Embar waters in its very low calcium content and absence of magnesium. The sulphate radicle predominates and the water is essentially a solution of sodium sulphate with small quantities of sodium chloride, sodium bicarbonate, and calcium bicarbonate.

Tensleep water can be differentiated from Embar water by its much greater quantity of calcium and magnesium, a chloride content of less than 15 parts per million, and a higher bicarbonate content.

Oregon Basin.—At Oregon Basin about 260 feet of Embar formation occurs 3,100–3,600 feet below the surface. A gradation from redbeds to limestone occurs, followed by limestone and shale above the zone of oil saturation. Broken beds of calcareous shale and limestone follow and merge into the Tensleep sandstone. In the earlier history of the field many wells were drilled into the Tensleep, and the Embar and Tensleep produced oil together. For this reason water samples obtained were ordinarily mixed. The Embar samples in this paper are uncontaminated, having been taken from wells drilled only to that formation.

Water is produced with the oil, the quantity of water varying from 1 to 90 per cent. Some structurally high wells produce 60 per cent water, whereas other wells structurally low yield less than one per cent water. This is probably caused by partial exhaustion of the oil and an abnormally high water level that has fingered in through more porous strata.

Analyses 374–378, inclusive, are from wells on the south end of the north dome, well up on structure; analysis 379 is from an unproductive well on the west edge of the south dome.

The water averages 60 per cent primary salinity, 25 per cent secondary alkalinity and 15 per cent secondary salinity. Hydrogen sulphide, even though unreported, is commonly present in those waters associated with oil. The concentration and chloride content are higher in the one well on the flank of the structure.

Embar water can be easily distinguished from Frontier water by the large proportions of calcium, magnesium, and sulphate contained by the Embar. The Chugwater water, with a concentration of 30,000 parts per million or more, can not be confused with the lower concentrated Embar water. It is believed that there are characteristic features between the waters of the Embar and Tensleep, but the lack of Tensleep samples precludes separating them now. As the early practice in this field of producing the Embar and Tensleep formations together has cast doubt on the identification of Tensleep samples, no analyses of the latter are given.

Hamilton dome.—The Embar formation contains the main oil-producing zone at Hamilton dome. It lies about 2,300–2,800 feet below the surface and has a thickness of 300–380 feet. It consists of limestone, reddish shale, sandy limestone, anhydrite, and gypsum. Analyses 380–384 are from wells on the downthrown side of a fault that seems to have affected the production in the field. Analysis 385 is from a well on the upthrown side of the same fault.

The Embar water at Hamilton dome is more concentrated than

that at Oregon Basin and contains a far greater proportion of chloride and about one-half as much magnesium. Some trouble has been encountered in field operations because this water deposits calcium sulphate on the inside of working barrels and in the lower parts of tubing, thereby sticking the traveling valves.

The water represented by analysis 380 was obtained about a year after the well was acidized and secondary salinity and secondary alkalinity occupy 30 per cent of the chemical system, which is twice as much as any other sample shows.

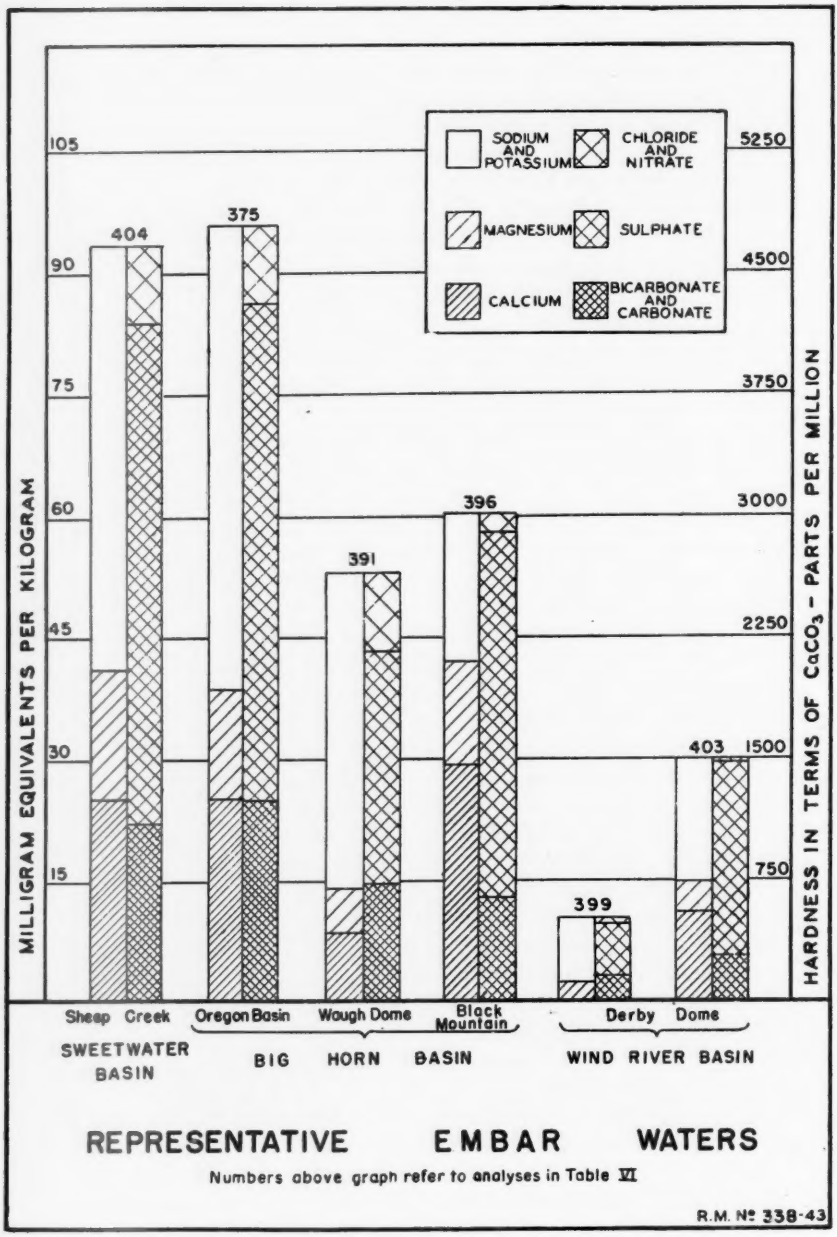
The higher concentration and the presence of the alkaline earths in the Embar water differentiates it from Frontier water. The exceptionally high concentration of water from the Chugwater formation distinguishes it from Embar water.

Waugh dome.—Only two wells have been drilled to the Embar on Waugh dome, and the second well logged it at depths of 3,881–4,168 feet, a total thickness of 287 feet. The formation consists largely of limestone and sandy limestone, with some calcareous shale near the bottom. Well No. 1, in Table VI, originally produced 582 barrels of clean oil daily, but in 2 years went to water. Well No. 2 had only a showing of oil in the Embar.

The five analyses of Embar water from well No. 1 are listed in Table VI chronologically, the first sample having been obtained, October 10, 1935, shortly after the completion of the well. Subsequently, that is, to October 2, 1937, the well was plugged back 18 feet and acidized, after which analyses 387–389 were taken. It is evident that acidization did not change the basic character of the water but increased its concentration and alkalinity. The increased concentration is caused by the addition of calcium bicarbonate, calcium chloride, and a small quantity of sodium salts, all of which have been dissolved from the acidized limestone.

The Tensleep and Embar waters are very similar but can be distinguished by the bicarbonate radicle, that of the former being less than 100 parts per million.

Thermopolis area.—The well from which analysis 392 was obtained was drilled a few miles south of the town of Thermopolis near the mouth of Wind River Canyon. A sand in the Embar was found at a depth of 250 feet and the well flowed 18,000 barrels of potable water a day, being a good example of artesian Embar water in the Big Horn Basin. The Embar crops out at the mouth of the canyon, about a mile from the well, and the Wind River is the source of the water. It has been reported that the flow of water from this well is high when the river is high and low when the river is low.



REPRESENTATIVE EMBAR WATERS

Numbers above graph refer to analyses in Table VI

R.M. Nº 338-43

FIG. 18

East Warm Springs dome.—A secondary saline Embar water has been obtained from one of the old wells at East Warm Springs, which originally produced oil. The formation consists largely of limestone and sandy limestone with calcareous shale near the base.

Analysis 293 shows that this water has the greatest percentage of secondary salinity of any Embar water sampled in the Big Horn Basin and resembles that at Waugh dome.

Black Mountain field.—The Embar formation at Black Mountain has variable porosity and zones of high and low permeability. Its thickness is about 300 feet and it lies about 2,900 feet below the surface. It consists of limestone and sandy limestone, with red shale near the base.

Eight wells have been drilled at Black Mountain, but only two produced oil in the Embar, although all were located favorably on the structure. Lenticular zones of variable permeability, and the consequent interfingering of water, cause wells higher structurally to produce water while lower wells produce clean oil.

Embar water from well No. 2 is a typical limestone water and is closely correlative with other Embar waters in the Big Horn Basin. The water from well No. 1 is an unusual Embar water because of the absence of the alkaline earths, which apparently were precipitated as carbonates because of improper sampling. Hydrogen sulphide is present in all samples.

Tensleep water at Black Mountain is easily distinguished from Embar water by its concentration of less than 1,000 parts per million total solids and by the absence of hydrogen sulphide.

WIND RIVER BASIN

Lander field.—The Lander structure is sharply folded and the Embar formation occurs in wells at a depth of about 1,200 feet; it consists of some 400 feet of cherty limestone, calcareous sand, and shale. As sections of very hard, dense limestone are present in the formation, its waters are discontinuous vertically and, consequently, vary considerably in character.

The Embar water analyses in Table VI were obtained from producing oil wells. The dilution of these waters suggests rapid circulation which would have flushed oil trapped in the structure. For this reason it is believed that the small amount of water produced with the oil enters the Embar from the Tensleep sandstone. The similarity of Tensleep and Embar waters substantiates this belief, and it is possible that the Tensleep water entered the Embar through old, improperly plugged wells. Analyses 397 and 398 do not, therefore, represent typi-

cal Embar water in this field; in fact, because this field, as well as others in the Lander area, is relatively old and because the available well logs are incomplete and inaccurate, it is difficult to determine exactly the stratigraphic positions within the Embar of the oil and water zones.

The simplest method of differentiating the chemically similar Embar and Tensleep waters is by the volume of flow, the latter being under a high artesian head with a yield varying from 5,000 to 30,000 barrels a day and the former rarely more than 50 barrels a day.

Derby dome.—Derby dome is similar to the Lander structure, though less sharply folded. The faulted Embar formation is about 345 feet thick in the wells and on top of the structure it lies 800 feet below the surface. Analyses 399–401 are from wells on top of this structure and 402 and 403 from wells on the flanks. All wells produce oil and water.

The dilute water associated with Embar oil is probably Tensleep water that has entered the Embar formation through improperly plugged wells. Analyses 402 and 403 show two to three times more concentration than the dilute water and a highly increased sulphate content, resembling Embar water in the Big Horn Basin. The well from which these samples were obtained found the top of the Embar at 1,942 feet and the bottom at 2,055 feet. The water just filled the casing and is believed to be true Embar water.

The means of distinguishing between the Embar and Tensleep waters at Derby dome is the same as in the Lander field. Tensleep water is artesian, and flows from 5,000 to 30,000 barrels a day.

SWEETWATER BASIN

Sheep Creek structure.—Analysis 404 represents a water sample taken from a well on the Sheep Creek structure in association with oil. The top of the Embar was logged at a depth of 2,185 feet and the bottom at 2,255 feet, the formation consisting of gray limestone and dolomite. The water probably comes from the contact of the Embar and Tensleep.

This water is heavily saturated with hydrogen sulphide and has about the same concentration and other characteristics as Embar water at Oregon Basin.

SUMMARY

The distinguishing feature of Embar water is the large proportion of calcium and magnesium sulphates. It contains, by far, more secondary salinity and alkalinity than any water previously considered in this paper.

In the Big Horn and Sweetwater basins the concentration ranges from 3,000 to 16,000 parts per million, with hydrogen sulphide present where associated with oil. In the Lander area of the Wind River Basin the Embar water is thought to be Tensleep water that has entered the Embar through improperly plugged wells.

WATERS OF TENSLEEP SANDSTONE AND EQUIVALENT UNITS

The Tensleep sandstone, of Pennsylvanian age, underlies the Embar formation and consists largely of 100–400 feet of massive, gray, white, brown, fine-grained, porous sandstone. It is a rather uniform body of sand with great variations in the amount of cementing material between the grains, and produces much oil and water in the state. The Tensleep is equivalent to an unknown part of the Minnelusa sandstone of eastern Wyoming.

Tensleep waters show some similarity to Embar waters, but are more uniform, have lower chloride and bicarbonate content and a dominant secondary salinity. In some parts of the state Tensleep water is dilute and potable, but the average Tensleep water has a concentration ranging from 1,500 to 4,000 parts per million. Hydrogen sulphide commonly occurs in this water.

BIG HORN BASIN

Frannie oil field.—Most of the oil in the Frannie field comes from the Tensleep sandstone, though a small amount comes from the Madison limestone. The Tensleep consists of about 250 feet of sandstone and limestone lying at an average depth of 2,500 feet below the surface. Analyses 405–409, in Table VII, represent samples from wells on top of the dome; of these, well No. 3-X is the only one that now produces oil.

Secondary salinity makes up 50–77 per cent of the chemical system and secondary alkalinity 8–22 per cent of this water at Frannie dome, which is a typical Tensleep water. The water from the "Dakota group" is distinguished from this water by its lower concentration and the absence or very low content of calcium and magnesium.

Byron field.—In one well in the Byron field the top of the Tensleep lies 5,710 feet below the surface. At a depth of 5,735 feet the sand yielded only water and the well was plugged back to 5,719 feet. The well was apparently down structure on the Tensleep water line.

This water is similar to Tensleep water in the Frannie field, correlating particularly well with analysis 409. Secondary salinity distinguishes it from Embar water, its closest counterpart, and additional differentiation lies in the extremely low chloride content of the Tensleep water as against 300 parts per million in Embar water.

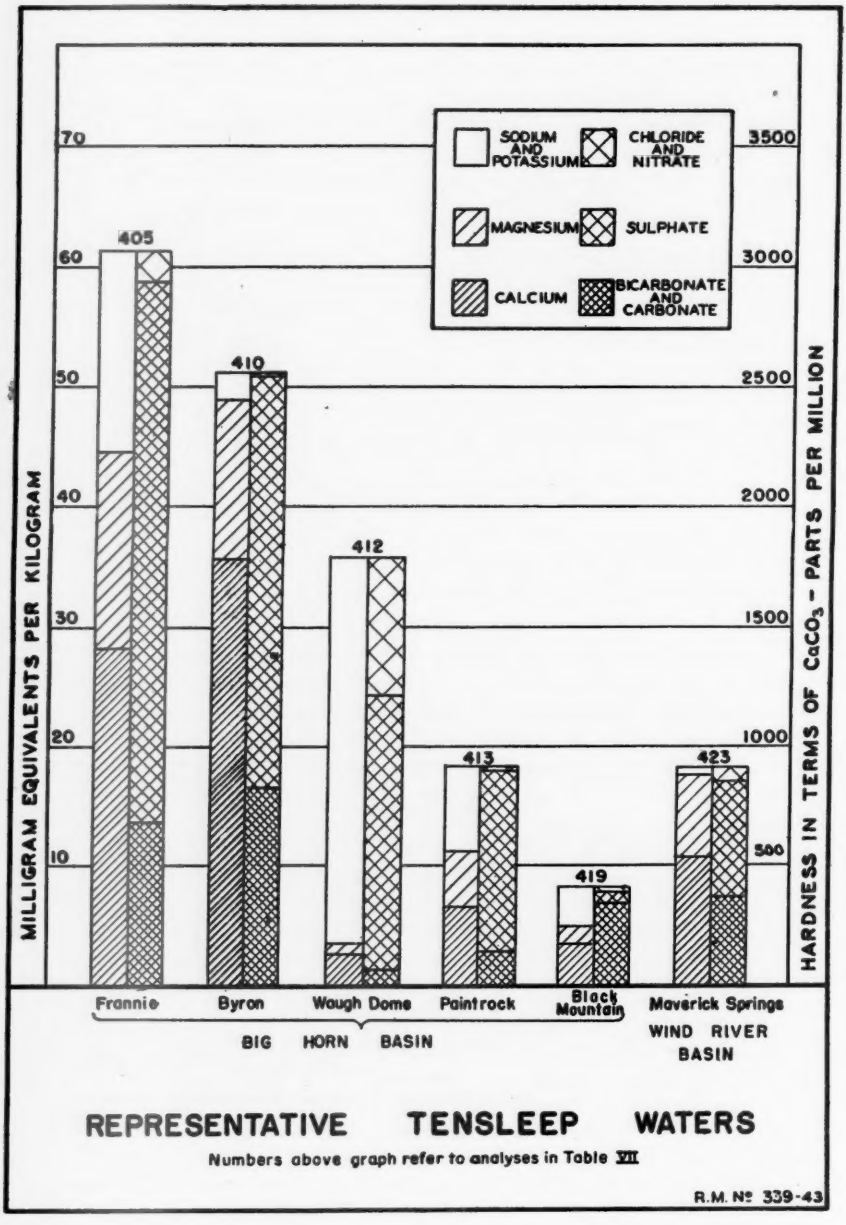

MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
70
60
50
40
30
20
10
3500
3000
2500
2000
1500
1000
500
SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
405
410
412
413
419
423
Frannie
Byron
Waugh Dome
Paintrock
Black Mountain
Maverick Springs
BIG HORN BASIN
WIND RIVER BASIN
REPRESENTATIVE TENSLEEP WATERS
Numbers above graph refer to analyses in Table VII
R.M. Nº 339-43

FIG. 19

Waugh dome.—The oil at Waugh dome was produced from the Embar formation, but the two wells penetrated the Tensleep sandstone, encountering water with a showing of oil in its upper part. However, analyses 411 and 412 inadequately illustrate characteristics of Tensleep water in this field because Embar water may not have been properly cased off.

Paintrock anticline.—About 110 feet of Tensleep sandstone, consisting of red, gray, and green sandstone, and sandy shale, is present in the Paintrock anticline, logged in one well at a depth of 1,795 feet. As no oil was encountered in the sandstone, wells drilled on this structure were usually left as water wells.

Paintrock anticline lies on the east side of the Big Horn Basin and the Tensleep sandstone crops out on the west slope of the Big Horn Mountains with the result that more dilute water than usual is present, although Tensleep characteristics are unmistakable. The water from the Madison limestone is easily confused with Tensleep water, the essential chemical differences between the two being the somewhat higher concentration and the total absence of magnesium in the former. The most important difference, though, is in the volume of water, as the Madison yields as much as 100,000 barrels of water a day, and the Tensleep wells flow much smaller volumes.

Tensleep anticline.—Only one well, now plugged and abandoned, has been drilled on the Tensleep anticline. This well logged the Tensleep sandstone at 3,015–3,312 feet, consisting of buff and pink calcareous sand. The main water sand was logged at 3,100 feet.

This water is typical Tensleep water, marked by high secondary salinity and low bicarbonate, the latter distinguishing it from Embar water. A sample of Amsden water was obtained from this well and its very dilute concentration of 450 parts per million distinguishes it from the Tensleep water.

Black Mountain field.—The Tensleep sandstone lies about 3,160 feet deep in the Black Mountain field and consists of 300 feet of white and reddish brown sandstone with breaks of sandy shale.

The Black Mountain field is one locality where Embar and Tensleep waters are sufficiently different to be easily identified. In contrast to Embar water with a concentration of 3,500 parts per million or more and a high calcium content is the dilute, almost potable, secondary alkaline water of the Tensleep sandstone. The concentration of Tensleep water ranges from 300 to 600 parts per million, secondary alkalinity makes up 60 per cent of the chemical system, and a chloride content of less than 20 parts per million is present.

Analysis 417 is marked by 61 per cent secondary salinity, but is

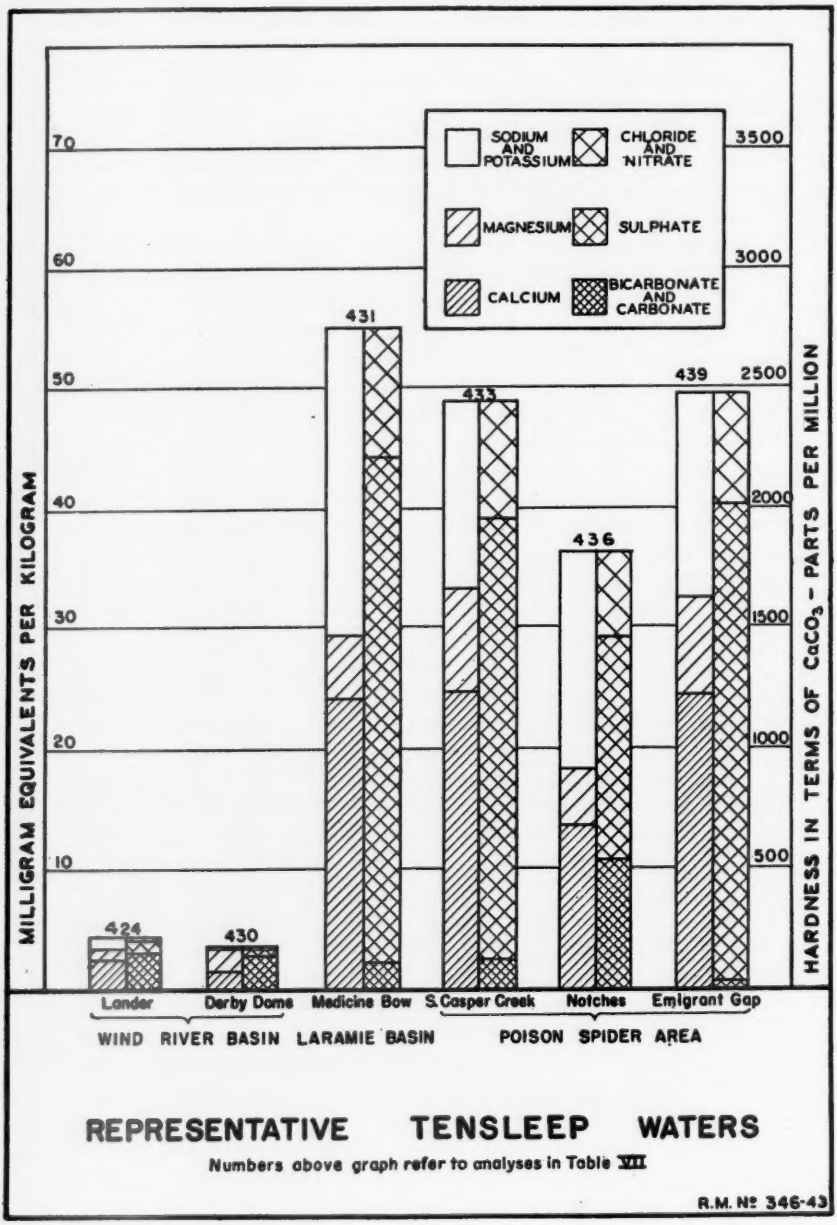

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
70
60
50
40
30
20
10
3500
3000
2500
2000
1500
1000
500
424
430
431
433
436
439
Lander
Derby Dome
Medicine Bow
S. Casper Creek
Notches
Emigrant Gap
WIND RIVER BASIN
LARAMIE BASIN
POISON SPIDER AREA
REPRESENTATIVE TENSLEEP WATERS
Numbers above graph refer to analyses in Table VII
R.M. Nº 346-43

FIG. 20

definitely Tensleep water. The additional calcium sulphate in this water may have come from a small quantity of Embar water that leaked past the casing-shoe, as the sample was obtained from a drilling well.

WIND RIVER BASIN

Maverick Springs field.—The oil in the Maverick Springs field is from the Embar formation and the Tensleep sandstone, the latter consisting of massive gray, white and brown sandstone, with thin breaks of limestone. Although no wells have drilled through the Tensleep in this field, its thickness is about 300 feet.

Analyses 422 and 423 in Table VII were taken from drilling wells which encountered water in the Tensleep and later plugged back to the oil-producing Embar. The water is essentially a solution of calcium and magnesium salts and has 55 per cent secondary salinity and 44 per cent secondary alkalinity. Primary salinity averaged only one per cent in the two samples.

Lander field.—As much as 500 feet of Tensleep sandstone has been logged in the Lander field because of the steep inclination of the beds. The top of the Tensleep is found at a depth of about 1,700 feet on the crest of the anticline. The field lies close to the Wind River Mountains, on the flanks of which the Tensleep sandstone crops out.

Oil occurs in the upper part of the Tensleep sandstone at Lander and artesian water in the base. Analysis 424 came from a well that found 20,000 barrels of water a day in the base of the Tensleep. The water is dilute and potable, and is identical with Embar water as previously discussed. The distinguishing feature of the Tensleep water is its large volume, varying from 5,000 to 30,000 barrels a day. Few Embar wells produce more than 50 barrels of water a day.

Dallas dome.—Reservoir conditions at Dallas dome are the same as in the Lander field. A showing of oil and a flow of 10,000 barrels of water per day were encountered in the well represented by analysis 426. Here, as at Lander, the Tensleep and Embar waters are positively distinguished only by the volume of their flows, the Embar wells flowing only a few barrels a day.

Derby dome.—At Derby dome the Tensleep sandstone lies about 1,200 feet deep on the crest of the structure. Wells near the apex of the structure produce oil, but lower wells yield only artesian water.

Well No. 2 on the flanks of the structure logged the Tensleep sand at a depth of 1,700 feet and encountered a flow of water estimated to be 2,500 barrels a day. The water is dilute, potable, and free of the hydrogen sulphide found in water higher on the structure.

TABLE VII

TENSLEEP SANDSTONE WATERS

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
													BIG HORN BASIN													
405	*Frannie	1	SW 24	56N	98W	3,800	384	564	197	2,159	90	- -	825	16.66	28.15	16.20	44.95	2.54	- - -	13.52	27.30	50.54	- - -	22.16	5.35	94.65
406	*Frannie	3X	NW 25	56N	98W	2,869	181	534	134	1,761	85	12	370	7.85	26.65	11.02	36.66	2.40	0.40	6.06	17.24	68.56	- - -	14.20	6.52	93.48
407	*Frannie[a]	36	NW 25	56N	98W	3,434	67	752	166	2,160	10	- -	568	3.20	37.60	13.70	44.90	0.30	- - -	9.30	5.80	77.20	- - -	17.00	0.90	99.10
408	*Frannie	36	NW 25	56N	98W	3,356	206	639	128	2,230	28	- -	691	8.98	31.89	10.53	46.43	0.79	- - -	4.18	17.40	74.40	- - -	8.20	1.52	98.48
409	*Frannie[a]	1	NE 25	56N	98W	3,723	51	760	240	2,303	27	- -	691	2.30	38.00	19.70	47.80	0.80	- - -	11.40	3.80	77.00	- - -	19.20	1.80	98.20
410	*Byron	4	NE 22	56N	97W	3,065	45	735	161	1,641	9	- -	1,005	1.95	35.69	13.24	34.16	0.25	- - -	16.47	3.84	63.80	- - -	32.36	0.74	99.26
411	Waugh Dome	1	NE 12	44N	97W	2,318	435	342	15	961	317	- -	505	18.92	17.07	1.23	20.01	8.94	- - -	8.27	50.84	26.94	- - -	22.22	30.88	69.12
412	Waugh Dome	2	NW 7	44N	96W	2,353	742	50	13	1,099	410	- -	80	32.18	2.50	1.07	22.88	11.56	- - -	1.31	90.00	6.34	- - -	3.66	33.57	66.43
413	Paintrock Anticline	1	SE 16	49N	90W	1,168	163	135	53	720	11	- -	175	7.07	6.74	4.36	14.99	0.31	- - -	2.87	38.90	45.30	- - -	15.80	2.02	97.98
414	Paintrock Anticline	2	SW 20	49N	90W	1,103	173	116	46	699	11	- -	195	7.49	5.79	3.95	13.72	0.31	- - -	3.20	43.48	37.94	- - -	18.58	2.21	97.79
415	*Tensleep Anticline	1	NW 13	46N	89W	3,698	267	776	56	2,510	60	- -	60	11.59	38.73	4.61	52.26	1.69	- - -	0.98	21.10	77.12	- - -	1.78	3.14	96.86
416	*Black Mountain	1	SW 25	43N	91W	365	51	68	19	28	12	- -	380	2.20	3.39	1.56	0.58	0.34	- - -	6.23	12.88	- - -	17.88	69.24	37.02	62.98
417	*Black Mountain[a]	1	SE 26	43N	91W	971	52	220	28	542	14	- -	235	2.19	11.00	2.30	11.20	0.39	- - -	3.80	14.20	61.00	- - -	24.80	31.90	68.10
418	*Black Mountain	1	NW 36	43N	91W	461	70	78	20	92	12	- -	385	3.03	3.89	1.65	1.92	0.34	- - -	6.31	26.36	- - -	9.00	64.64	15.01	84.99
419	*Black Mountain	2	SE 36	43N	91W	435	74	76	16	44	16	- -	425	3.23	3.79	1.32	0.92	0.45	- - -	6.97	16.44	- - -	22.28	61.28	32.90	67.10
420	*Black Mountain	2	SE 36	43N	91W	261	20	41	30	21	6	Tr	287	0.85	2.05	2.47	0.44	0.23	- - -	4.70	12.48	- - -	3.34	84.18	34.34	65.66
421	*Black Mountain[a]	3	31			627	144	48	31	175	7	- -	452	6.26	2.40	2.54	3.61	0.19	- - -	7.40	33.90	- - -	22.00	44.10	5.00	95.00
													WIND RIVER BASIN													
422	*Maverick Springs[a]	1	SW 23	6N	2W	1,448	- -	340	101	617	40	- -	682	- - -	17.00	8.20	12.80	1.10	- - -	11.30	- - -	55.20	- - -	44.80	8.00	92.00
423	Maverick Springs[a]	1	SE 26	6N	2W	1,051	15	224	67	469	36	- -	457	0.40	11.10	7.10	9.80	1.10	- - -	7.60	2.00	57.00	- - -	41.00	10.20	89.80
424	Lander	7	NW 30	8S	2E	247	34	48	12	60	6	- -	190	1.15	2.39	0.99	1.25	0.17	- - -	3.11	29.46	5.96	- - -	68.86	11.91	88.09
425	*Lander	8	NW 30	8S	2E	375	111	38	Tr	38	67	- -	245	4.80	1.90	- - -	0.79	1.89	- - -	4.02	40.00	- - -	31.64	28.36	70.50	29.50
426	Dallas Dome	1	NE 13	32N	99W	314	41	46	20	67	29	- -	220	1.79	2.40	1.64	1.40	0.82	- - -	3.61	30.70	7.38	- - -	61.92	36.92	63.08
427	*Derby Dome	12	SW 4	31N	98W	212	10	42	24	Tr	3	Tr	270	0.44	2.09	1.97	- - -	0.08	- - -	4.42	1.78	- - -	8.00	90.22	100.00	- - -
428	*Derby Dome	2	NE 4	31N	98W	198	9	36	20	- -	12	Tr	220	0.41	1.89	1.64	- - -	0.34	- - -	3.60	8.64	- - -	1.78	89.58	100.00	- - -
429	Derby Dome	2	NE 9	31N	98W	167	22	44	- -	12	10	- -	160	0.95	2.20	- - -	0.25	0.28	- - -	2.62	16.32	- - -	14.48	69.20	53.47	46.53
430	Derby Dome	2	NE 9	31N	98W	182	4	35	22	22	3	- -	195	0.16	1.74	1.81	0.46	0.08	- - -	3.19	4.82	9.66	- - -	85.52	14.78	85.22
													LARAMIE BASIN													
431	Medicine Bow	3A	NE 26	21N	79W	3,618	605	475	63	2,024	385	- -	135	26.32	23.71	5.18	42.14	10.86	- - -	2.21	47.68	48.32	- - -	4.00	20.49	79.31
432	Big Hollow	1	NE 30	15N	75W	3,083	785	205	11	1,881	135	- -	135	34.05	10.23	0.91	39.17	3.81	- - -	2.21	75.34	19.76	- - -	4.88	8.87	91.13

Number	LOCATION					PARTS PER MILLION							MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
													POISON SPIDER AREA												
433	*South Casper Creek		NE 3	33N	83W	3,120	356	493	103	1,752	345	- -	145	15.50	24.61	8.47	36.47	9.73	- - -	2.38	32.00	63.20	- - -	4.80	21.61	78.99
434	South Casper Creek	2	33	33N	83W	2,716	445	328	92	1,330	394	- -	135	18.32	16.37	7.57	28.94	11.11	- - -	2.21	43.36	51.40	- - -	5.24	27.73	72.27
435	*Notches[a]	2	SW 3	37N	85W	2,335	254	436	74	1,020	287	- -	551	10.70	21.50	6.05	21.20	8.05	- - -	9.00	28.00	48.40	- - -	23.60	27.40	72.60
436	*Notches[a]	2	NW 10	37N	85W	2,244	425	264	58	900	281	- -	638	18.50	13.30	4.70	18.76	7.22	- - -	10.52	50.70	20.50	- - -	28.80	27.83	72.17
437	Notches[a]	2	NW 10	37N	85W	2,035	308	216	110	781	350	- -	600	13.50	10.90	9.60	16.00	9.00	- - -	9.00	39.90	33.62	- - -	26.48	36.20	63.80
438	*Notches[a]	1	NE 10	37N	85W	1,965	448	220	Tr	668	350	- -	566	22.20	10.90	- - -	13.90	9.90	- - -	9.30	66.60	5.40	- - -	28.00	41.75	58.25
439	Emigrant Gap	2	NW 23	34W	82W	3,232	397	482	100	1,910	331	- -	25	17.23	24.06	8.22	39.77	9.33	- - -	0.41	34.80	64.36	- - -	0.84	19.00	81.00
440	Emigrant Gap	1	SE 23	34W	82W	3,395	405	443	92	1,972	339	- -	94	17.46	27.11	7.57	41.06	9.56	- - -	1.54	33.54	63.50	- - -	2.96	18.88	81.12
441	Emigrant Gap	1	NE 26	33W	81W	3,692	471	541	116	2,112	400	- -	105	20.42	27.01	9.54	43.97	11.28	- - -	1.72	35.84	61.14	- - -	3.02	20.41	79.59
													POWDER RIVER BASIN												
442	Knycee Dome	3	SE 4	43N	82W	2,918	508	350	100	1,068	825	- -	135	22.03	17.47	8.22	22.24	23.27	- - -	2.21	46.16	49.20	- - -	4.64	51.13	48.87
443	Tisdale	1	SE 16	41N	81W	2,551	516	231	85	1,057	605	- -	115	22.45	11.53	6.99	22.01	17.07	- - -	1.89	54.80	40.58	- - -	4.62	43.68	56.32
444	*Salt Creek	12X	SW 25	40N	79W	3,110	626	370	55	1,114	872	- -	149	27.22	18.46	4.52	23.17	24.59	- - -	2.44	54.22	40.92	- - -	4.86	51.50	48.50
445	Salt Creek	8Tp	SE 26	40N	79W	2,574	504	305	48	1,031	629	- -	115	21.93	15.22	3.95	21.47	17.74	- - -	1.89	53.36	42.04	- - -	4.60	45.24	54.76
446	Salt Creek	.8Tp	NW 35	40N	79W	2,836	456	378	82	1,231	604	- -	170	19.85	18.86	6.74	25.63	17.03	- - -	2.79	43.68	50.18	- - -	6.14	39.92	60.06
447	Salt Creek	26Tp	NW 35	40N	79W	3,566	684	432	84	1,209	1,076	- -	165	29.74	21.57	6.91	25.17	30.34	- - -	2.71	51.08	44.26	- - -	4.66	54.66	45.34
448	Salt Creek[a]	29Dt	NW 35	40N	79W	2,561	438	319	61	1,050	570	- -	123	19.00	16.00	5.00	21.90	16.10	- - -	2.00	47.40	47.60	- - -	5.00	42.30	57.70
449	Middle Creek	1	SW 32	34N	65W	567	46	73	50	259	58	- -	165	1.99	3.64	4.11	5.39	1.64	- - -	2.71	20.42	51.76	- - -	27.82	23.33	76.67
450	Lance Creek	10	5	35N	65W	2,594	240	465	68	1,684	73	- -	130	10.45	23.21	5.59	35.06	2.06	- - -	2.13	26.62	69.96	- - -	5.42	5.56	94.44
451	Lance Creek	1	SE 35	36N	65W	2,350	367	385	52	1,269	260	- -	160	15.97	16.12	4.28	26.42	7.33	- - -	2.62	43.92	48.88	- - -	7.20	21.72	78.28
452	Lance Creek	A-3	SW 5	35N	65W	1,947	486	169	Tr	966	270	- -	110	21.13	8.44	- - -	20.16	7.61	- - -	1.80	71.46	22.46	- - -	6.08	27.41	72.59
453	[c]Town of Hulett	1	7	54N	64W	505	5	108	44	179	21	- -	300	0.23	5.39	3.62	3.73	0.59	- - -	4.92	2.48	44.28	- - -	53.24	13.67	86.33
454	[c]Town of Sundance	1				931	2	160	94	532	5	- -	280	0.07	7.99	7.73	11.06	0.14	- - -	4.59	0.56	70.40	- - -	29.04	1.24	98.76
455	Pump Creek	1	SW 12	47N	64W	3,910	81	723	252	2,764	36	- -	110	3.54	36.09	20.73	57.54	1.02	- - -	1.80	5.86	91.16	- - -	2.98	1.74	98.26

[a] Analyses courtesy Midwest Refining Company.
[b] Analysis by Producers and Refiners Company, Parco, Wyoming.
[c] In Black Hills region.
* Hydrogen sulphide present.

LARAMIE BASIN

Medicine Bow oil field.—The oil in the Medicine Bow field comes from the Sundance formation. The well represented by analysis 431 logged the top of the Tensleep at a depth of 7,003 feet, and the bottom at 7,518 feet. This sample was taken with a Halliburton tester seated at a depth of 7,003 feet.

Secondary salinity is the predominating characteristic of this water, which is easily distinguished from Sundance water by its much greater concentration and by the presence of notable quantities of calcium and magnesium.

Big Hollow structure.—In the Big Hollow field the top of the Tensleep sandstone was logged at a depth of 2,543 feet. Analysis 432 was obtained through a drill stem test with seat at 2,543 feet and bottom at 2,579 feet. The well was later plugged and abandoned.

The Tensleep water at Big Hollow, in the southern part of Laramie Basin, though somewhat lower in secondary salinity, resembles Tensleep water in the Medicine Bow field at the north edge of the basin. The alkalinity in both waters is the same, the only variation being a lower secondary saline content in the Big Hollow water.

The dilute upper Cloverly water in this structure is distinguished from Tensleep water by its low concentration and the absence of the alkaline earths.

POISON SPIDER AREA

South Casper Creek field.—The only oil-producing sand in the South Casper Creek field is the Tensleep sandstone, which is logged at depths of 2,300–2,500 feet below the surface. The formation is 250 feet thick, the first 60 feet consisting of bedded sandstone and the rest of massive, cross-bedded sandstone.

Typical secondary saline water is found in the Tensleep at South Casper Creek. The water not only correlates with other Tensleep waters in the Poison Spider area, but is decidedly similar to Tensleep waters in the Laramie Basin. Secondary salinity distinguishes this water from all higher waters.

Notches field.—The only oil-producing sand at Notches is the Tensleep, which is about 250 feet thick and occurs at an average depth of 2,750 feet below the surface. Wells in this field are bottomed 10–50 feet in the sand. Well No. 1, in the NE. $\frac{1}{4}$, Sec. 10, T. 37 N., R. 86 W., was drilled to a depth of 2,840 feet, and water flowed over the casing. The well was then plugged back to 2,776 feet, where the base of the oil-saturated zone was found.

The Dakota (?) water at Notches is distinguished from the secondary saline Tensleep water by the practical absence of the alkaline earths and by its lower concentration.

Emigrant Gap structure.—As there are local "highs" on the Emigrant Gap structure, the wells vary considerably in depth. In well No. 2, NW. ¼, Sec. 23, T. 34 N., R. 82 W., the Tensleep sandstone was logged at 2,240–2,620 feet, or a total thickness of 380 feet.

Water is the only fluid in the Tensleep sandstone at Emigrant Gap, one well flowing 1,000 barrels a day. Secondary salinity, so typical of Tensleep water, dominates the chemical system.

POWDER RIVER BASIN

Kaycee dome.—Most of the wells on Kaycee dome log the top of the Tensleep sandstone at a depth of about 1,700 feet, though the well represented by analysis 442 logged it at 1,760 feet and encountered a flow of 13,000 barrels of water a day. This well was drilled into the Amsden formation and abandoned.

The Tensleep water here is similar to Tensleep water in the Poison Spider area, secondary salinity being the predominant characteristic. Tensleep water from the Tisdale anticline and the Salt Creek oil field is correlated with this water, demonstrating the remarkable uniformity of Tensleep waters in the state.

Tisdale structure.—The Tisdale "high," a few miles southeast of Kaycee dome, also produced artesian water from the Tensleep sandstone. The most remarkable well in this field is the Shiloh well, SE. ¼, Sec. 16, T. 41 N., R. 81 W., which at a depth of 2,195 feet yielded in the Tensleep sandstone an artesian flow estimated at 133,000 barrels a day and reported to have risen 11 feet above the top of the 10-inch casing.

This water, practically identical chemically with Tensleep water at Kaycee dome, was piped to the Salt Creek oil field and used in field operations and distilled for drinking water for many years. It is still used for irrigation by ranchers and farmers in the Tisdale area.

Secondary salinity is prominent in this water and hydrogen sulphide is found in the fresh water at the well. Although the water is hard it was formerly used in boilers in the Salt Creek oil field, where it was found that the scale deposited was soon redissolved if soft water was occasionally used in the boilers.

As the Tensleep sandstone in the Salt Creek oil field is cemented with calcareous material and contains cavernous streaks, such as are commonly found in limestone, it is possible that the tremendous artesian flow encountered at Tisdale was caused by the drill tapping one of the larger and more extensive cavernous portions of the sandstone.

Salt Creek oil field.—The first well drilled to the Tensleep sandstone in the Salt Creek oil field encountered a flow of 27,000 barrels

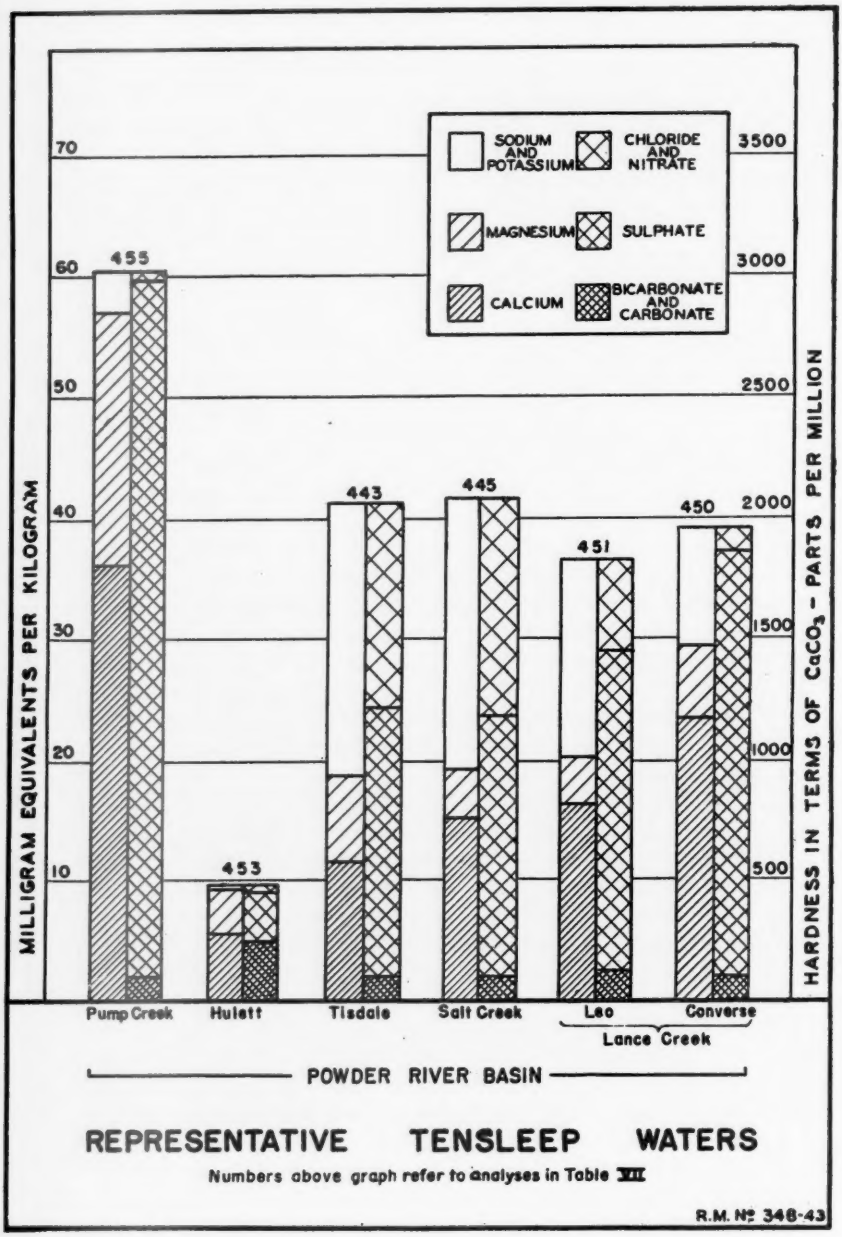

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
70
60
50
40
30
20
10
3500
3000
2500
2000
1500
1000
500
455
453
443
445
451
450
Pump Creek
Hulett
Tisdale
Salt Creek
Leo
Converse
Lance Creek
POWDER RIVER BASIN
REPRESENTATIVE TENSLEEP WATERS
Numbers above graph refer to analyses in Table XII
R.M. № 348-43

FIG. 21

of water a day, with a temperature of 176°F. The well was drilled in 1926 just outside the clean oil contour of the Lakota sand.

In 1930 a second well was drilled through the Tensleep sandstone, and had an initial production of 1,900 barrels of oil in the Tensleep. This well drilled to granite, and is the only well in the field to penetrate all the Tensleep sandstone. The well was later plugged back and completed as a Tensleep producer.

The Tensleep sandstone in the aforecited deep test consists of about 300 feet of massive cross-bedded white, pink, and gray quartzitic sandstone that is highly cemented with calcium carbonate, contains cavernous portions similar to limestone, and thin layers of dark brown limestone. The contact between the Tensleep sandstone and the Amsden formation was not sharply defined in this well.

Other wells drilled to the Tensleep sandstone in 1937 and 1938 were located structurally higher than the well just described and it was the practice to drill about 175 feet into the sand and perforate the casing near the oil-water contact.

Tensleep water is the most dilute subsurface water in the Salt Creek field and is marked by high secondary salinity. The chloride content averages about 650 parts per million and in general there is an excess of sodium. Bicarbonate is very low, averaging about 150 parts per million. These characteristics distinguish Tensleep water from other surface or subsurface waters in the Salt Creek oil field.

The higher chloride in analysis 447 is present as a result of acidization of the well. Both wells, No. 8-Tp and No. 26-Tp, NW. $\frac{1}{4}$, Sec. 35, T. 40 N., R. 79 W., were acidized and the latter was not washed clean when sampled.

Middle Creek structure.—An exceptional type of Minnelusa water for the Powder River Basin occurs in the Middle Creek structure, about 15 miles south of the Lance Creek oil field. The Minnelusa was logged at a depth of 1,407 feet, where a dilute, potable water was encountered. Like most Tensleep water, this sample is marked by high secondary salinity. Its low concentration, in comparison with Minnelusa water from the Lance Creek oil field, is caused principally by proximity of the sand to the surface and a very free water movement in the sand, which is probably fed by seepage from the North Platte River. Only a small quantity of water was encountered in this well, which was later plugged back to the Fall River sandstone as a water well.

Lance Creek oil field.—The total thickness of the Minnelusa (Pennsylvanian) formation in the Lance Creek oil field is more than 1,200 feet, and its top is logged at an average depth of 4,900 feet. The first sand in the formation—the Converse—is about 40 feet thick and

produces commercial quantities of oil, although it is at present shut in. Most of the Minnelusa oil is produced from the Leo sand, lying about 500 feet below the Converse sand.

The latest information available on the Minnelusa formation in Lance Creek is as follows. For the purpose of unitization, the Minnelusa formation, about 1,200 feet thick, has been tentatively separated into (1) the Converse sand, about 435 feet thick from the top of the Minnelusa to a red shale marker common in Lance Creek and other fields in eastern Wyoming; (2) the Leo sand, about 600 feet thick, including one or two ordinarily well saturated sands, beginning about 100 feet below the red shale marker and originally thought to be all of the Leo sand; another sand (called the "Joss" when first found) about 150 feet below the top of the Leo sand; other saturated zones; and (3) the Bell sand, about 165 feet thick, at the base of the Minnelusa.

Analysis 450, in Table VII, is from the Converse sand; analyses 451 and 452 are from the Leo sand. It is noticeable that the Converse and Leo waters are very similar, have characteristic Tensleep composition, and differ mainly in the chloride content. More samples will be necessary before a definite differentiation can be made between the two waters, but these three analyses suggest that a lower chloride content distinguishes the Converse water from the Leo.

Both Converse and Leo waters are distinguished from Sundance water at Lance Creek by their lower concentration, and particularly by the typically Tensleep characteristic of low bicarbonate. The Fall River water in this field contains neither calcium nor magnesium, which distinguishes it from both Sundance and Minnelusa waters.

Pump Creek structure.—A well drilled on the Pump Creek structure encountered showings of oil and considerable water in the Minnelusa sandstone, which was logged at 1,535 feet and consisted of gray and pink limestone and yellow sandstone. Water encountered at a depth of 1,560 feet is represented by analysis 455, in Table VII.

A water exceptionally high in secondary salinity occurs in the top of the Minnelusa in this structure. Its characteristics are somewhat similar to Converse water in the Lance Creek field, but it is exceptional to find that the reacting values of the calcium and magnesium almost exactly balance the reacting value of the sulphate radicle, as they do in this water.[7] The somewhat higher concentration of the water suggests a more restricted water movement in the sand than at Lance Creek.

[7] Several water samples from the Minnelusa sand at Newell, South Dakota, show this exceptional feature.

Black Hills region.—In a water well drilled at Hulett, the top of the light gray Minnelusa sandstone was found at a depth of 646 feet. The well was drilled to 663 feet, where a flow of 13,000 barrels a day of dilute, potable water was encountered. Secondary alkalinity is the dominant characteristic of this water, but secondary salinity, a typical Tensleep characteristic, is also prominent.

At the town of Sundance the Minnelusa sandstone was found at 160 feet, and consisted of varicolored limestone, sandy limestone, and sandstone. Water was encountered in the base of the formation but not in sufficient quantity to supply the town. The well was drilled to the Deadwood formation (Cambrian) and abandoned. The little water encountered is similar to that found at Hulett, but more concentrated. Secondary salinity comprises 70 per cent of the chemical system.

SUMMARY

Tensleep waters are noted for their uniformity in chemical composition throughout the state. With the exception of some dilute waters in various scattered areas, the ordinary Tensleep water is a secondary saline type with a concentration varying from 1,500 to 4,000 parts per million. Hydrogen sulphide is commonly present, but not in any great quantity. Another feature of the Tensleep water is its low bicarbonate content, seldom reaching 500 parts per million, more commonly less than 300 parts per million. This is one feature that in some fields differentiates Tensleep water from Embar water.

Secondary salinity is the important and distinguishing characteristic of Tensleep waters in the Big Horn Basin. The water from the Black Mountain field is the only exception, a dilute, secondary alkaline water occurring there.

In the Wind River Basin secondary salinity and secondary alkalinity predominate to the almost total exclusion of the primary characteristics, an exceptional condition for natural water. A very dilute water in which secondary alkalinity is foremost occurs in the Lander area of this basin, which is distinguished by the large volume of water produced, flows varying from 5,000 to 30,000 barrels a day being common.

Only two samples of Tensleep water have been obtained in the Laramie Basin. Secondary salinity, although it does not dominate the chemical system, is appreciable, and the water is further marked by the low bicarbonate radicle typical of so many Tensleep waters.

Secondary salinity is the principal characteristic of Tensleep waters in the Poison Spider area and in the Powder River Basin where the bicarbonate is low.

TABLE VIII

Madison Limestone Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
													BIG HORN BASIN													
456	*Garland	3	NE 34	56N	98W	2,494	34	536	138	1,500	198	tr	175	1.47	26.86	11.35	31.23	5.58	- - -	2.87	3.70	89.06	- - -	7.24	15.15	84.85
457	Garland	3	NW 29	56N	97W	1,893	336	288	13	731	511	- -	24	14.58	14.37	1.07	15.22	14.41	- - -	0.39	48.56	50.14	- - -	1.30	48.65	51.37
458	Garland	1	- 28	56N	97W	3,738	213	721	179	1,936	648	12	60	9.26	35.99	14.72	40.31	18.28	0.40	0.98	15.44	82.26	- - -	1.84	31.20	68.80
459	*Garland	1	SW 28	56N	97W	3,984	479	666	136	1,469	957	tr	525	20.84	34.25	11.10	30.59	27.00	- - -	8.60	31.48	55.52	- - -	13.00	46.89	53.11
460	*Garland	1	SE 29	56N	97W	1,064	134	184	36	334	302	- -	150	5.80	9.18	2.96	6.96	8.52	- - -	2.46	32.32	53.96	- - -	13.72	55.04	44.96
461	*Garland	1-B	SW 34	56N	97W	4,270	580	705	135	1,621	1,071	8	366	23.94	35.19	11.10	33.75	30.21	0.27	6.00	34.08	57.00	- - -	8.92	47.23	52.77
462	*Garland	1	SW 34	56N	97W	2,960	290	801	136	1,524	426	tr	230	11.32	39.01	11.18	31.73	12.01	- - -	3.77	23.82	68.24	- - -	7.94	27.46	72.54
463	Garland	3	33	56N	97W	3,446	400	530	138	1,626	734	- -	37	17.35	26.46	11.36	33.85	20.71	- - -	0.61	31.44	67.46	- - -	1.10	37.96	62.04
464	*Garland	1				3,053	129	639	144	1,583	432	18	220	5.61	31.90	11.84	32.96	12.18	0.60	3.61	11.36	80.10	- - -	8.54	26.98	73.02
465	*Garland	1-B				4,096	309	873	133	1,567	967	- -	465	13.44	43.57	10.94	33.04	27.28	- - -	7.63	19.78	68.98	- - -	11.24	45.22	54.76
466	*Garland	1	33	56N	97W	3,117	462	382	139	1,471	420	tr	495	20.10	19.06	11.43	30.63	11.84	- - -	8.12	39.74	40.20	- - -	16.06	27.87	72.13
467	*Garland	1	3	55N	97W	2,872	76	599	145	1,746	276	tr	60	3.29	29.90	11.92	36.35	7.78	- - -	0.98	7.30	90.52	- - -	2.18	17.63	82.37
468	*Torchlight	1	SE 19	51N	92W	272	20	58	23	- - -	9	- -	330	0.88	2.89	1.89	- - -	0.25	- - -	5.41	4.42	- - -	11.12	84.46	100.00	- - -
469	Torchlight	1	SE 19	51N	92W	257	54	46	- -	47	4	tr	215	2.32	2.30	- - -	0.98	0.11	- - -	3.53	23.60	- - -	26.62	49.78	10.17	89.83
470	Paintrock	1	NW 12	49N	91W	1,731	163	377	- -	1,100	4	- -	176	7.09	18.81	- - -	22.90	0.11	- - -	2.89	27.38	61.46	- - -	11.16	0.47	99.53
471	Zeiseman Dome	1	SW 23	49N	89W	633	186	65	tr	179	38	- -	335	7.05	3.24	- - -	3.73	1.07	- - -	5.49	46.64	- - -	21.88	31.48	22.28	77.72
472	Red Springs	1	SW 28	43N	93W	2,954	80	646	171	1,405	234	- -	850	3.47	32.25	14.06	29.25	6.60	- - -	13.93	6.98	65.04	- - -	27.98	9.66	90.34
473	Red Springs	1	SW 28	43N	93W	2,072	180	388	122	607	244	- -	1,080	7.82	19.37	10.03	12.64	6.88	- - -	17.70	21.02	31.42	- - -	47.56	35.24	64.76
													POWDER RIVER BASIN													
474	Town of Sundance[c]	1				577	33	16	104	194	58	tr	310	1.41	0.80	8.55	4.04	1.64	- - -	5.08	13.10	39.68	- - -	47.22	28.86	71.14

* Hydrogen sulphide present.
[c] In Black Hills region.

In the Black Hills region dilute, potable water is found where no structures exist that will allow trapping of formation waters. In those structures capable of retaining oil or gas, Minnelusa water similar to the more concentrated waters of other parts of the state is found.

MADISON LIMESTONE WATERS

The Madison limestone, of Mississippian age, is the oldest sedimentary formation in the state that has produced commercial quantities of oil and gas. It produces black oil in the Big Horn Basin and has yielded showings of oil in northeastern Wyoming. In many parts of the state the Madison has never been tested. One well in the Salt Creek oil field found a showing of black oil in the Madison, which was reported to consist of vari-colored sandstone, limestone, and shale, with dolomite at the base.

Madison waters range from a very dilute, potable water to one with a concentration of 4,000 parts per million. Secondary salinity is the prominent characteristic, though the more dilute waters show some primary and secondary alkalinity. In general, Madison waters are typified by their high percentage of calcium and magnesium sulphates, resembling Embar and Tensleep waters in many respects.

Like the Embar formation, the Madison limestone is often acidized, which changes the concentration and characteristics of its water to some extent.

BIG HORN BASIN

Garland dome.—The Madison limestone is the main producing formation at Garland, yielding oil, gas, and water. The formation consists of cherty limestone at the top, thin layers of cherty limestone throughout, and zones of porous limestone and calcareous sandstone between the cherty sections; anhydrite and shaly limestone also occur in the formation.

Oil has been obtained as low as 500 feet below the top of the Madison at Garland, although some wells produce from a horizon 100 feet in the limestone. The top of the formation is found at an average depth of 4,000 feet on the axis of the structure.

The Madison water at Garland is definitely a secondary saline type and is somewhat erratic in composition and concentration, varying from 1,000 parts per million to 4,000 parts per million. Acidization of the limestone has affected the composition of the formation water. Another factor influencing the water production in this field is the uneven permeability of the producing section, which results in partial exhaustion of the oil in certain strata within an area drained by a well, and the subsequent interfingering of water. As in the Embar

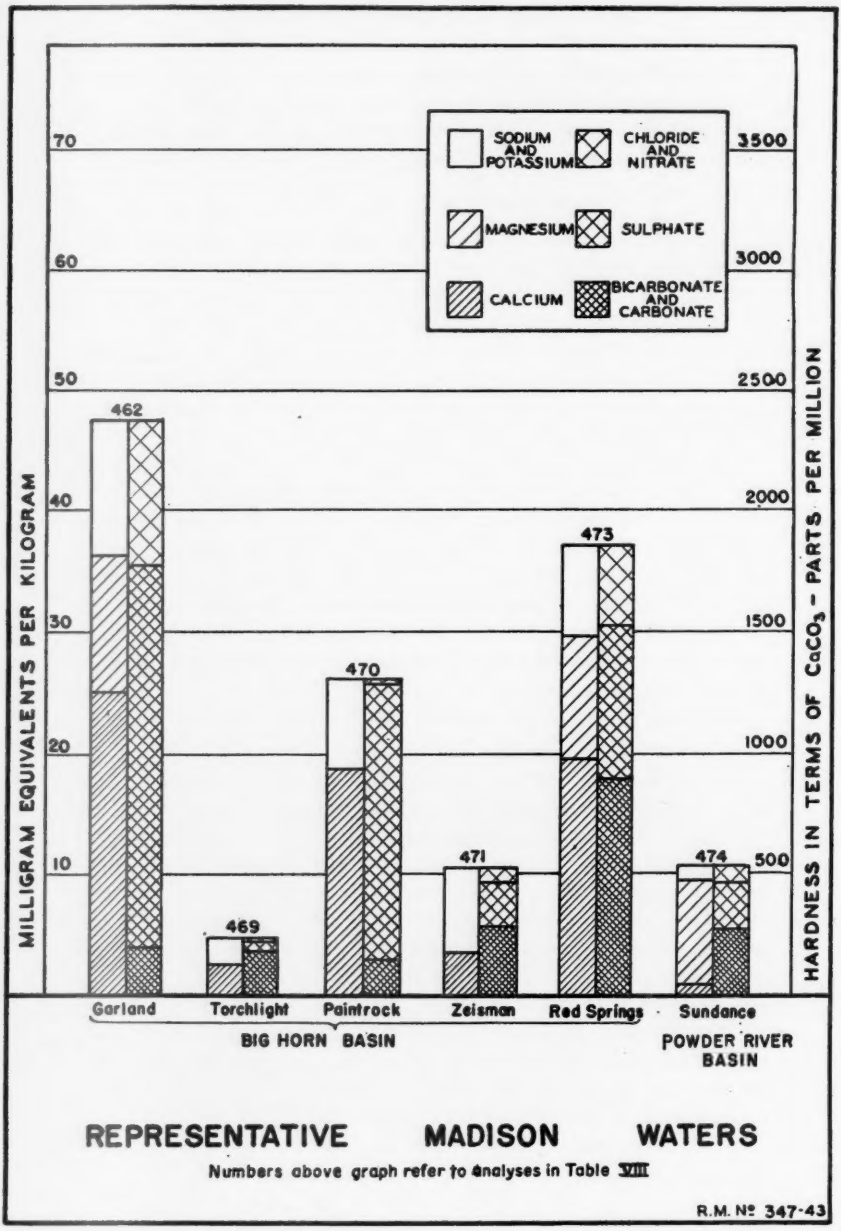

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
70
60
50
40
30
20
10
3500
3000
2500
2000
1500
1000
500
462
469
470
471
473
474
Garland
Torchlight
Paintrock
Zeisman
Red Springs
Sundance
BIG HORN BASIN
POWDER RIVER BASIN
REPRESENTATIVE MADISON WATERS
Numbers above graph refer to analyses in Table VIII
R.M. Nº 347-43

FIG. 22

formation, water zones in the Madison lie above, below, and between oil zones.

The Frontier water is the only other subsurface water sampled in the field, so, regardless of the erratic nature of the Madison water, there is no difficulty in distinguishing the two. The Frontier water is a primary alkaline type, calcium, magnesium, and sulphate being absent. The Madison water is the opposite, calcium and magnesium sulphates being the dominant salts.

Torchlight field.—The Madison limestone in the Torchlight field produced a showing of oil and an artesian flow of potable water estimated at 10,000 barrels a day in one edge well. The contact between the Amsden formation and the Madison limestone was not definitely established, but was thought to be at about 3,860 feet. At 3,864–3,870 feet the first water (analysis 468) was found which flowed from the top of the casing at an estimated rate of 15 barrels a day. The well was shut down for about 30 days and a small amount of oil began showing in the water. In drilling deeper a heavy artesian flow was struck at 4,068 feet.

The first sample contained hydrogen sulphide, due perhaps to its association with oil. The second sample indicates a freedom of flow unassociated with oil, with a probable source of fresh water in the Big Horn Mountain uplift. Although the two analyses differ in minor respects, the source of both waters is the same.

A concentration of more than 2,000 parts per million in Greybull water at Torchlight distinguishes it from Madison water. In addition, Greybull water contains no calcium or magnesium.

Paintrock anticline.—Penetration of the Madison limestone 147 feet in one well produced an artesian flow varying from 80,000 to 100,000 barrels of water a day on the Paintrock anticline. The top of the limestone was logged at 2,150 feet. The water is of the secondary saline type, and is marked by the absence of magnesium, thus partaking of the character of the Madison water at Torchlight. Its greater concentration indicates a slower water movement in the formation.

Tensleep water from abandoned wells at Paintrock has been sampled. The two waters are chemically similar, the Madison water being more concentrated and containing a greater quantity of calcium sulphate than the Tensleep. Both formations crop out on the slope of the Big Horn Mountains east of the field, and their source waters are, therefore, the same.

Zeisman dome.—The top of the Madison limestone was logged at a depth of 283 feet in the one well drilled on this structure, and water stood 50 feet in the hole. Though about twice as concentrated, this

water is chemically comparable with the artesian Madison water in the Torchlight field. Both waters are noted for their primary alkalinity, being the only Madison waters so marked. The water is dilute, indicating a rapid water movement in the formation, and its source is the Big Horn Mountains.

Red Springs structure.—When a well on the Red Springs structure was drilled into the Madison limestone in 1938, very little water was produced with a few barrels of heavy black oil. The top of the limestone was logged at a depth of 902 feet, and the small oil production was found at 1,082 feet, where analysis 472 was obtained. The well was deepened to 1,100 feet where a larger quantity of water, represented by analysis 473, was encountered. Both waters are typical Madison waters, but the latter is more dilute, indicating a less restricted water movement in the formation. It is apparent that the first showing of water was a more stagnant one associated with dead oil. With a greater length of time in contact with the limestone it picked up added calcium and magnesium sulphates. Upon deepening the well, a less stagnant water was yielded, as evidenced by its lower calcium and magnesium sulphate content.

BLACK HILLS REGION

Town of Sundance.—The Pahasapa (Madison of some reports) limestone has yielded a little oil in northeastern Wyoming, but deep water samples obtained there have never been definitely correlated with it. The only known Pahasapa sample came from a well drilled in the town of Sundance. The limestone was reached at a depth of 750 feet and water was encountered at 1,260 feet, 1,000 feet of water standing in the hole.

The Pahasapa crops out in the Black Hills uplift from which it receives an ample supply of fresh, potable water. The water, as encountered in the well at Sundance, is typical of a limestone water with calcium and magnesium sulphate dominating the chemical system. In this water the magnesium ion is greater than the calcium ion, a somewhat exceptional condition in natural waters.

SUMMARY

In the more concentrated Madison waters of the Big Horn Basin secondary salinity is the main characteristic. In these waters the concentration ranges from 1,700 parts per million to 4,000 parts per million. In the more dilute waters of the basin, that is, those waters whose concentration does not exceed 1,000 parts per million, primary alkalinity dominates.

Insufficient samples have been obtained from northeast Wyoming to even generalize, but it seems that secondary salinity and secondary alkalinity dominate Pahasapa water there as they do in the equivalent Madison of the Big Horn Basin.

MISCELLANEOUS WATERS

Several water samples have been collected from formations in Wyoming that are present only locally or have been tested in only one or two widely scattered areas. Many such analyses may be a key as to the type of water to expect in other parts of the state but, unfortunately, generalization can not be made on such meager evidence.

MESAVERDE FORMATION WATERS

The Mesaverde formation, of Upper Cretaceous age, consists in general of upper and lower sandstone members separated by shale and sandy shale. The upper member consists of light gray sandstone interbedded with shale, sandy shale, and coal. The lower member consists of sandstone interbedded with shale and sandy shale.

Seventy-five barrels of water per hour were obtained from the Mesaverde near the Grass Creek oil field at the depth of 240 feet. Primary salinity and secondary alkalinity predominate, but the character of the water may vary considerably because of surface-water intrusion.

Secondary salinity, averaging 60 per cent of the chemical system, predominates in Mesaverde water from the Alkali Butte field. This water was unsuitable for boiler use because of the large amount of permanent hardness. A yield of fifty-five barrels per hour was reported from the sand at a depth of about 500 feet.

A dilute water, averaging between 12 and 15 grains per gallon in hardness, flowed from the basal Mesaverde sand at depths ranging from 2,000 to 2,100 feet in the syncline east of the Medicine Bow oil field. Originally flowing about 75 barrels per hour, the wells now pump 30–60 barrels an hour, augmenting the supply normally drawn from the Medicine Bow River.

EAGLE SANDSTONE WATER

In parts of the Elk Basin oil field the Eagle sandstone, of Upper Cretaceous age, produces 100 barrels of water a day per well at depths averaging 250 feet. The water is of the primary saline type, with 94 per cent of the salinity caused by the sulphate radicle, and will probably vary considerably over the structure because of its proximity to the surface with consequent surface-water dilution.

TABLE IX

Miscellaneous Water Sands

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
											MESAVERDE FORMATION WATERS															
475	Big Horn Basin: Grass Creek	2	NW 30	46N	98W	1,864	480	87	85	650	21	- -	1,100	20.82	4.34	6.99	13.53	0.59	- - -	18.03	43.92	- - -	20.84	35.24	4.18	95.82
476	Wind River Basin: Alkali Butte	1	SE 25	34N	95W	2,644	120	317	284	1,560	36	- -	665	5.22	15.82	23.36	32.48	1.02	- - -	10.90	11.76	63.70	- - -	24.54	3.00	97.00
477	Alkali Butte	2	SE 25	34N	95W	2,215	102	239	268	1,195	32	- -	770	4.43	11.93	22.04	24.68	0.90	- - -	12.62	8.86	58.28	- - -	32.86	3.40	96.60
478	Laramie Basin: Medicine Bow	1	NE 30	21N	78W	817	220	66	Tr	384	9	- -	280	9.55	3.29	- - -	8.00	0.25	- - -	4.59	64.24	- - -	10.14	25.62	3.01	96.99
479	Medicine Bow	2	NE 30	21N	78W	786	170	57	30	389	11	6	250	7.39	2.85	2.47	8.10	0.31	0.20	4.10	58.14	8.02	- - -	23.84	3.67	96.33
											EAGLE SANDSTONE WATERS															
480	Big Horn Basin: Elk Basin		32	58N	99W	3,922	1,303	40	20	1,963	80	- -	1,049	56.67	2.00	1.65	40.87	2.26	- - -	17.19	71.50	- - -	22.44	6.06	5.23	94.77
481	Elk Basin					3,675	1,324	7	8	1,181	112	77	1,358	58.00	0.40	0.70	31.10	3.20	2.60	22.20	58.00	- - -	40.20	1.80	7.00	93.00
											MOWRY SHALE WATERS															
482	Big Horn Basin: Hamilton Dome	1	NE 13	44N	98W	8,073	4,110	- -	- -	3,395	47	- -	1,060	89.39	- - -	- - -	70.69	1.33	- - -	17.37	80.56	- - -	19.44	- - -	1.84	98.16
											FORT UNION FORMATION WATERS															
483	Big Horn Basin: Nolber Dome	1	19	45N	92W	1,637	531	24	- -	743	83	- -	395	23.08	1.20	- - -	15.47	2.34	- - -	6.47	73.36	- - -	21.70	4.94	13.14	86.86
484	Nolber Dome	2	19	45N	92W	1,862	622	36	- -	871	70	- -	535	27.06	1.80	- - -	18.13	1.97	- - -	8.76	69.64	- - -	21.12	6.24	9.79	90.21
											STEELE SHALE WATERS															
485	Wind River Basin: Pilot Butte	3	NW 27	3N	1W	14,910	5,894	26	46	- -	7,154	- -	3,640	256.38	1.30	3.78	- - -	201.80	- - -	59.66	77.18	- - -	20.80	1.94	100.00	- - -
486	Pilot Butte	2	NW 22	3N	1W	7,100	2,796	16	35	- -	3,400	- -	1,795	121.64	0.80	2.88	- - -	95.90	- - -	29.42	76.52	- - -	20.54	2.94	100.00	- - -
487	Alkali Butte		NW 26	34N	95W	7,007	2,805	- -	- -	- -	3,518	- -	1,390	122.02	- - -	- - -	- - -	99.23	- - -	22.79	81.32	- - -	18.68	- - -	100.00	- - -
											AMSDEN FORMATION WATERS															
488	Big Horn Basin: Tensleep Anticline	1	NW 13	46N	89W	461	75	91	Tr	133	83	81	- - -	3.26	4.54	- - -	2.33	2.33	2.69	- - -	41.66	23.78	- - -	34.56	45.72	54.28
489	Powder River Basin: Tisdale	33x	NW 28	41N	81W	1,964	468	80	114	484	742	- -	154	20.17	4.00	9.31	10.06	20.90	- - -	2.52	60.30	32.30	- - -	7.40	67.75	32.25

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
												GREENHORN LIMESTONE WATERS													
490	Powder River Basin: Osage	1	NE 16	46N	64W	19,092	7,320	142	29	63	11,322	- -	140	318.41	7.09	2.39	1.31	319.37	- - -	7.21	97.10	0.70	- - -	2.20	99.59	0.41
491	Osage	2	NE 15	46N	64W	20,387	7,902	62	41	53	12,054	- -	560	343.83	3.09	3.37	1.10	340.02	- - -	9.17	97.38	- - -	0.78	1.84	99.67	0.33
492	Osage	1	SW 15	46N	64W	18,383	7,064	90	52	66	10,882	- -	165	307.28	4.49	4.19	1.37	306.96	- - -	7.63	91.58	- - -	5.68	2.74	99.49	0.51
493	Osage	5U2	NE 14	46N	64W	9,726	3,818	34	Tr	- -	5,466	Tr	830	166.08	1.70	- - -	- - -	154.18	- - -	13.60	91.90	- - -	7.08	1.02	100.00	- - -
494	Osage	3	SE 14	46N	64W	10,970	4,238	55	26	- -	6,375	- -	575	184.36	2.75	2.14	- - -	179.83	- - -	9.42	95.02	- - -	2.40	2.58	100.00	- - -
495	Osage	12	SE 14	46N	64W	15,158	5,699	45	21	64	8,785	Tr	700	256.62	2.25	1.73	1.33	247.80	- - -	11.47	95.60	- - -	2.68	1.52	99.46	0.54
496	Osage	1	NW 23	46N	64W	18,204	7,021	53	54	134	10,735	Tr	420	305.40	2.65	4.44	2.79	302.81	- - -	6.09	97.74	0.06	- - -	2.20	99.08	0.92
497	Osage	3	NW 23	46N	64W	14,607	5,786	38	Tr	- -	8,550	50	495	249.06	1.90	- - -	- - -	241.17	1.67	8.12	96.10	- - -	3.14	0.76	100.00	- - -
498	Osage	3	NW 23	46N	64W	13,920	5,369	28	- -	925	7,333	24	490	233.55	1.40	- - -	19.26	206.85	0.80	8.04	96.24	- - -	3.16	0.60	91.48	8.52
499	Osage	13	NW 30	46N	63W	12,906	5,000	45	28	61	7,470	- -	615	217.51	2.25	2.30	1.27	210.71	- - -	10.08	95.46	- - -	2.48	2.06	99.39	0.61
500	Osage	9	SE 30	46N	63W	19,563	7,696	- -	- -	- -	11,856	- -	22	334.80	- - -	- - -	- - -	334.44	- - -	0.36	99.90	- - -	0.10	- - -	100.00	- - -
												CRETACEOUS FORMATION WATERS													
501	Big Horn Basin: Oregon Basin	1	SW 19	51N	100W	33,116	10,580	500	132	16,520	5,300	- -	170	460.01	24.96	10.86	343.53	149.50	- - -	2.79	92.80	6.64	- - -	0.56	30.37	69.63
502	Oregon Basin	2	NE 36	51N	101W	41,501	14,200	646	187	10,472	15,850	Tr	135	621.71	32.24	15.38	220.03	447.10	- - -	2.21	93.00	6.60	- - -	0.40	67.07	32.93
503	Hamilton Dome	4	NW 14	44N	98W	44,489	15,349	696	81	12,413	15,810	- -	285	667.58	34.74	6.66	258.44	445.97	- - -	4.67	94.16	5.18	- - -	0.66	63.31	36.69
												GREEN RIVER FORMATION WATERS													
504	Sweetwater Basin: Bridger Basin	1		15N	113W	64,446	27,145	- -	- -	81	12,000	19,700	11,225	1,180.78	- - -	- - -	1.69	338.50	656.61	183.98	28.80	- - -	71.20	- - -	99.74	0.26
505	Blacks Fork	1	NW 2	18N	116W	43,337	18,004	- -	- -	633	10,400	11,350	6,000	783.19	- - -	- - -	13.18	293.36	378.31	98.34	39.14	- - -	60.86	- - -	95.70	4.30
506	Green River	1	NW 26	18N	107W	59,523	21,796	- -	- -	909	13,176	17,975	5,425	1,078.62	- - -	- - -	18.93	371.66	599.12	88.91	36.23	- - -	63.78	- - -	95.13	4.87
507	Green River	1	NW 26	18N	107W	63,004	26,175	- -	- -	1,119	14,580	18,720	4,900	1,138.63	- - -	- - -	23.30	411.27	623.75	80.31	38.16	- - -	61.84	- - -	94.65	5.35
508	Green River	1	NW 26	18N	107W	65,054	27,134	- -	- -	930	14,040	19,950	6,100	1,180.34	- - -	- - -	19.36	396.04	664.96	99.98	35.20	- - -	64.80	- - -	95.32	4.68
509	Green River	1	NW 26	18N	107W	76,499	31,792	- -	- -	897	18,340	22,460	6,000	1,382.95	- - -	- - -	18.68	517.33	748.60	98.34	38.74	- - -	61.26	- - -	96.65	3.35
510	Green River	1	NW 26	18N	107W	54,471	22,699	- -	- -	1,115	12,150	16,600	4,000	988.79	- - -	- - -	23.21	342.73	553.29	65.56	37.16	- - -	62.84	- - -	93.65	6.35
511	Green River	1	NW 26	18N	107W	62,738	26,200	- -	- -	1,050	12,690	19,700	6,300	1,139.69	- - -	- - -	21.86	357.96	656.61	103.26	33.32	- - -	66.68	- - -	94.26	5.74
512	Green River	1	NW 26	18N	107W	66,826	27,811	- -	- -	1,605	13,770	21,280	4,800	1,209.78	- - -	- - -	33.41	388.42	709.28	78.67	34.88	- - -	65.12	- - -	92.05	7.95

* Analyses courtesy Midwest Refining Company.

** Analysis courtesy Producers and Refiners Corporation, Parco, Wyoming.

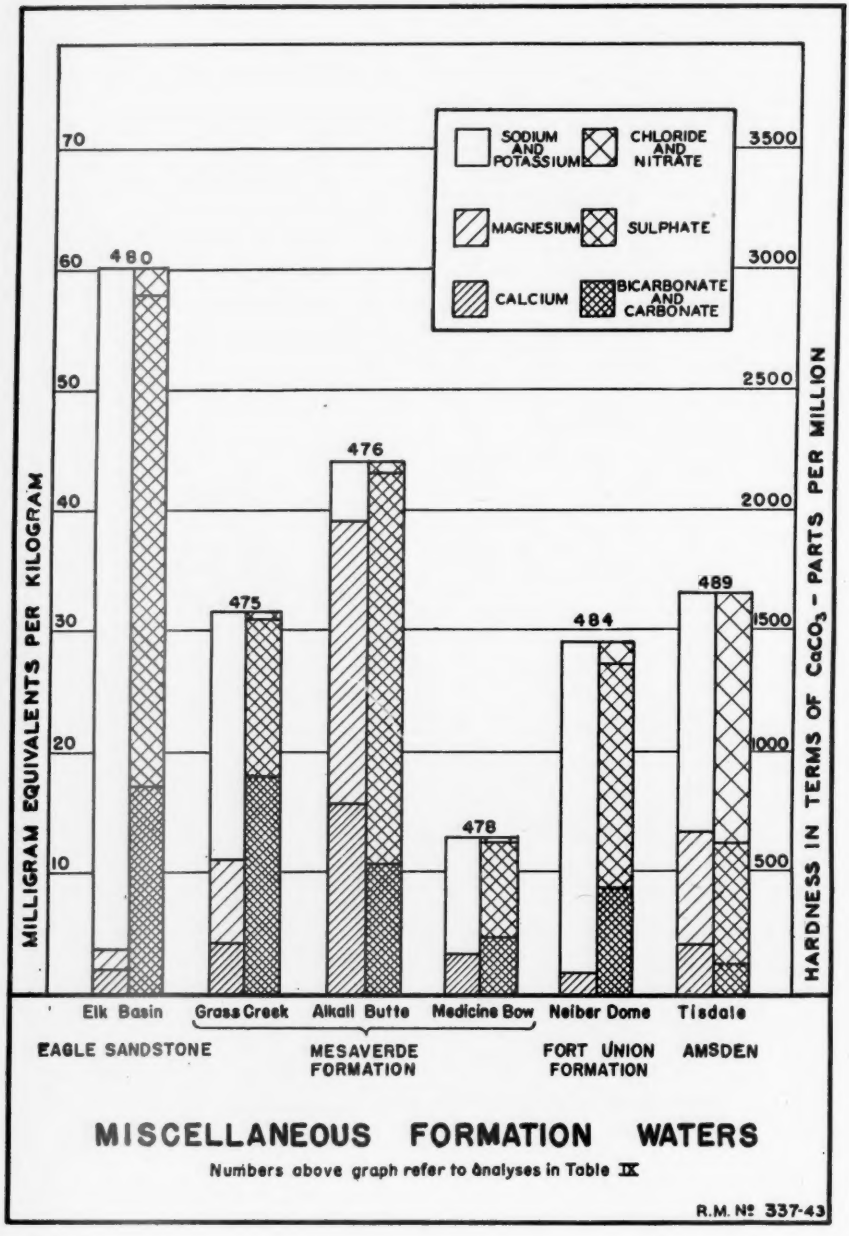

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
70
60
50
40
30
20
10
3500
3000
2500
2000
1500
1000
500
480
475
476
478
484
489
Elk Basin
Grass Creek
Alkali Butte
Medicine Bow
Nelber Dome
Tisdale
EAGLE SANDSTONE
MESAVERDE FORMATION
FORT UNION FORMATION
AMSDEN
MISCELLANEOUS FORMATION WATERS
Numbers above graph refer to analyses in Table IX
R.M. Nº 337-43

FIG. 23

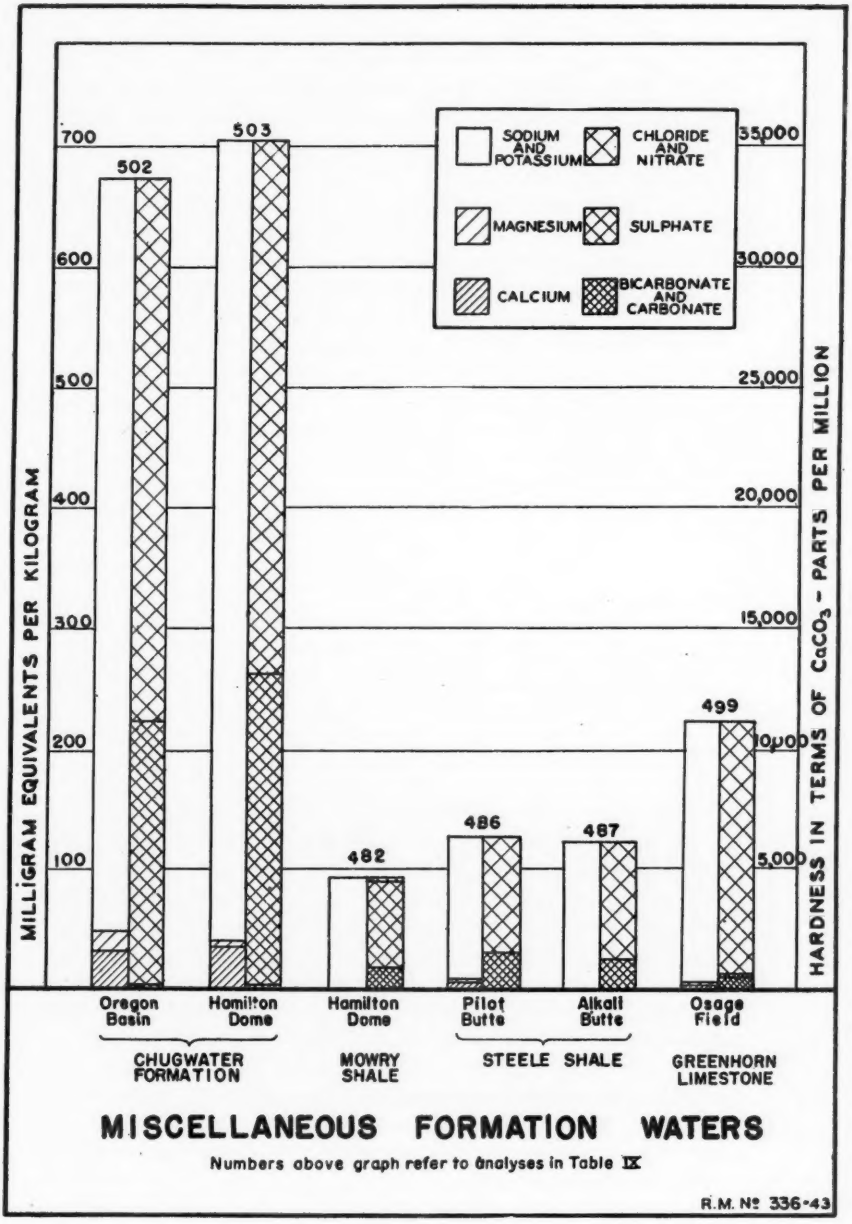

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
700
600
500
400
300
200
100
35,000
30,000
25,000
20,000
15,000
10,000
5,000
502
503
482
486
487
499
Oregon Basin
Hamilton Dome
Hamilton Dome
Pilot Butte
Alkali Butte
Osage Field
CHUGWATER FORMATION
MOWRY SHALE
STEELE SHALE
GREENHORN LIMESTONE
MISCELLANEOUS FORMATION WATERS
Numbers above graph refer to analyses in Table IX
R.M. Nº 336-43

FIG. 24

MOWRY SHALE WATERS

The Mowry shale, of Upper Cretaceous age, consists of hard, dark, fissile shale containing fossil fish scales and beds of bentonite. The Mowry is the surface formation at Hamilton dome and has an 8-foot water sand 152–160 feet below the top.

Analysis 482 was obtained from the cellar of a drilling well. This water closely resembles the softened Shannon water in the Salt Creek oil field, both being essentially solutions of sodium sulphate with minor quantities of sodium bicarbonate and sodium chloride.

The source of Mowry water is surface water which has leached calcium and magnesium sulphates from shale outcrops. Entering a sandstone bed at its outcrop, the heavily charged secondary saline water has been softened through contact with bentonite beds, the result being the primary saline water represented by analysis 482.

The identical cycle occurs in the Salt Creek oil field, where surface water impregnated with calcium and magnesium sulphate leached from the Steele shale is softened by contact with bentonite beds. The result is a Shannon water comparable with Mowry water.

FORT UNION FORMATION WATERS

Wells drilled about 200 feet into the Fort Union formation, of Paleocene age, at Neiber dome, encountered a moderately dilute primary saline water that was used in oil-field operations. Each well pumped 9–12 barrels of water per hour. The water contains relatively little temporary hardness and is essentially a solution of sodium sulphate, sodium bicarbonate, and sodium chloride.

STEELE SHALE WATERS

The three samples represented by analyses 485–487, in Table IX, came from a sandy zone in the Steele shale that approximately represents the Shannon sandstone of the Salt Creek area. In the Pilot Butte field this zone is sandy shale that produces all the oil in the field at depths ranging from 735 feet to 1,020 feet. The well represented by analysis 485 had an initial production of 20 barrels of oil per day, while that represented by analysis 486, considerably down the structure, found no oil.

This water is essentially a primary saline water, the higher concentration and higher chloride in analysis 485 being caused by its association with oil and consequent stagnancy. If concentration is ignored and reaction values in per cent used, analysis 485 is almost identical with analysis 486.

Only a showing of oil and 250 barrels of water per day were en-

countered in an old water well in the Alkali Butte field. The water is a little more saline than that at Pilot Butte, but in all other respects they are similar.

AMSDEN FORMATION WATERS

The Amsden formation, of Pennsylvanian and Missippian age, underlies the Tensleep sandstone and overlies the Madison limestone. Some oil has been produced from the Amsden in Montana and scattered areas in Wyoming, but in general the formation is dry.

In the Tensleep anticline the top of the Amsden formation was logged at a depth of 3,312 feet in the one well drilled on this structure, and the well bottomed in the formation with a hole full of water. This water, represented by analysis 488, is very dilute, indicating a freedom of flow far greater than in the Tensleep sandstone just above. As the Amsden is calcareous, the flow is apparently through cavities and fissures in the limestone, fed by fresh water from the Big Horn Mountains on the east. The Tensleep water, sampled from the same well, is a concentrated saline water that is easily differentiated from the dilute Amsden water.

In the Tisdale anticline the Amsden formation was logged at a depth of 2,300 feet and consists of 28 feet of hard, white sandstone followed by sandy limestone and vari-colored sandstone and limestone. The well represented by analysis 489 stopped drilling at 2,400 feet with a hole full of water. This water is chemically very similar to the artesian Tensleep water in the same field, but contains a smaller quantity of calcium sulphate.

GREENHORN LIMESTONE WATER

The Greenhorn limestone, of Upper Cretaceous age, in the Osage field consists of as much as 60 feet of thin-bedded, hard, gray limestone lying between the Carlile shale and the Graneros shale. Very little water occurs in the formation at Osage, the quantity ordinarily ranging from 6 barrels a day to 2 gallons a week per well. The top of the limestone is logged at depths varying from 0 to 1,000 feet at Osage.

The water is very concentrated, ranging from 10,000 to 20,000 parts per million, and is essentially a solution of sodium chloride with minor quantities of other salts. Calcium and magnesium are commonly present in small amounts. The water is perhaps a trapped and altered sea water, and it is highly probable that there is little, if any, ingress of fresh water to the formation.

The Greenhorn water can be easily differentiated from all surface or subsurface waters in the Osage field by its relatively high concentration.

CHUGWATER FORMATION WATERS

The Chugwater formation, often termed redbeds, of Permian and Triassic age, consists of massive red shale and sandstone, interbedded with some limestone and gypsum. About six wells in the state produce oil from the formation and some gas has been encountered, but generally the sandstones contain only water, or are dry.

In the Oregon Basin field the Chugwater ranges from 850 to 1,000 feet thick and contains some gas and oil. The water zone in the well represented by analysis 501 was reached at a depth of 3,415 feet, whereas west of the structure in the well represented by analysis 502 it was logged at 3,840 feet.

In the Hamilton dome field oil has also been found in the Chugwater formation. The formation averages 1,280 feet in thickness, and the sand from which analysis 503 was obtained was logged at a depth of 2,410 feet. This well is near a fault.

Redbeds water is distinctive and can not be confused with other subsurface waters. The water is more than 99 per cent saline, with a concentration varying from 33,000 to 45,000 parts per million, and closely resembles sea water. However, it differs from sea water in a lowered magnesium content and an increased sulphate content, alterations that could easily have taken place in the sand. The increased sulphate doubtless comes from gypsum beds.

The concentration of Chugwater water, at least in analyses 502 and 503, is greater than normal sea water, but that is caused by additional sodium sulphate in the formation water. It is believed that the few analyses of redbeds water given herein represent a trapped and partially altered sea water.

GREEN RIVER FORMATION WATERS

In the southwestern part of the state an exceptional type of water has been encountered in a few wells drilled into the lacustrine Green River formation, of Eocene age. The formation consists of sandstone, marl, limestone, and sandy shale. Thin beds of oil shale, halite, glauberite, and beds of trona ranging from less than an inch to a foot in thickness, are found in the formation. These deposits from an ancient lake give the formation water its exceptional character.

The Green River water, as encountered in drilling wells in this area, is marked by an exceptionally high content of normal carbonate, presumably obtained by the solvent action of ground water on the beds of trona in the formation. The normal carbonate ranges from 11,000 to 22,000 parts per million, accompanied by 6,000–11,000 parts per million of bicarbonate. Sodium carbonate occupies 60 per cent of the dissolved salt content of the water. Sodium chloride, derived from

the halite in the formation, makes up 37 per cent of the dissolved salt content. The remaining 3 per cent of dissolved solids is sodium sulphate, derived from glauberite. The average specific gravity of the water is 1.05–1.06, the total solids ranging from 40,000 to 76,000 parts per million.

The water is encountered only in a comparatively small area near the town of Green River, and its exceptional nature differentiates it from other surface or subsurface water in the state.

CONCLUSIONS

Oil-field waters in the Rocky Mountain region, as compared with other areas, are exceptionally low in concentration. In most of the waters of Wyoming the salinity is so low that little, if any, connection can be made with connate waters. Few of the saline waters of the state approach sea water in concentration and they are ordinarily found in the younger formations, as the Shannon and Frontier sandstones, sand bodies that are lenticular, discontinuous, and interbedded with shales. Even in these "streaky" sandstones few total solids reach 19,000 parts per million, one-half the concentration of sea water.

The deeper-seated waters of the state in those sandstones marked by continuous sheets are exceptionally low in chloride content, indicating very thorough leaching of the sea water originally present in the sands. The waters are wholly unrelated to connate water and the presence of relatively large percentages of secondary salinity, a characteristic of most of the surface waters of the state, is convincing evidence that the waters of these uniform "sheet" sandstones are surficial in origin. Any connate water that may have once been in these sands has long since been flushed out by meteoric waters.

The writer believes, from the evidence supplied by these analyses, that the oil-field waters of Wyoming, even in those sandstones of lenticular and discontinuous nature, have been considerably modified, and are now being modified, by the infiltration of surface water.

An important point in a study of oil-field waters is concentration, a factor that is controlled chiefly by the physical characteristics of the strata. Where the structure prevents free circulation of ground water, the formation water is more concentrated, but where circulation is relatively free, the formation water is dilute and of substantially the same character as that entering the sand at the outcrop. Concentration is thus a measure of water movement in the structure, and consequently a closed structure capable of retaining oil and gas contains a more concentrated water. A dilute water generally indicates a freedom of flow sufficient to have flushed oil and gas from a structure.

It would therefore be expected that the concentration of formation water would increase updip and reach its maximum at the oil-water contact. From the foregoing reasoning, it is suggested that the concentration and chloride content of formation waters is not a function of depth, but rather of the water movement in the sand, and will reach its maximum at or near the oil-water contact.

Instances of increase in concentration and salinity at the oil-water contact are found in several oil-producing fields in the state, the First Wall Creek sand water of the Salt Creek field being a good example, but there is not as yet sufficient evidence to draw general conclusions. The writer suggests, though, that such increase in concentration and salinity will be found in the Cretaceous, and probably Jurassic, waters of the state, whereas the secondary saline waters of the pre-Chugwater beds will not show this characteristic, to any marked extent.

Post-Chugwater waters are essentially solutions of sodium salts, whereas pre-Chugwater beds yield water in which calcium and magnesium sulphates predominate. Although there are several exceptions to this, caused principally by local geologic conditions, in general it is true that primary salinity and primary alkalinity dominate the chemical system of waters from post-Chugwater formations, and secondary characteristics predominate in waters from pre-Chugwater formations.

The depth of a producing sand body below the surface has little to do with concentration, but where the sand crops out either on or near the structure, it ordinarily yields waters that are essentially solutions of sodium sulphate. Examples of this type of water are the Shannon water in the Salt Creek field, the Eagle water at Elk Basin, the Mowry water at Hamilton dome, and the Fort Union water at Neiber dome. There are exceptions to this rule, dependent somewhat on the type of shale over which surface water flows to reach the outcrop, but in general formation waters close to the surface are of this type.

Frontier waters are solutions of sodium chloride and sodium bicarbonate in varying proportions, sulphate and the alkaline earths being present only as surface or drilling-water contamination. With but few exceptions the water is comparatively concentrated.

"Dakota group" waters are solutions of sodium salts, but contain appreciable quantities of sulphate, particularly in the more dilute waters. Potable water occurs in many areas in the Dakota and Lakota sands. Such oil production as comes from the "Dakota group" sands is yielded by the deeper-seated sand bodies, where a higher chloride water is found.

Sundance waters are ordinarily solutions of sodium salts similar, except for concentration, to Frontier and "Dakota group" waters. The principal Sundance sandstone is far more uniform in distribution than

the sands of the Frontier and "Dakota group," and the waters have more uniformity in concentration and chemical characteristics. This is the youngest formation water that contains hydrogen sulphide, and it appears only in water from the lower sandstone members.

The Chugwater formation acts as a dividing line between the primary waters of the formations above and the secondary waters of the formations below. Chugwater water, where sampled, is commonly concentrated, ranging from 30,000 to 50,000 parts per million, and can hardly be confused with formation waters lying above or below.

Embar waters are the highest subsurface waters discussed herein in which secondary salinity is prominent. Primary characteristics dominate the chemical system and secondary salinity occupies from 1 to 47 per cent. Hydrogen sulphide occurs in most Embar waters, particularly in those associated with black oil.

In most of the Tensleep waters sampled, secondary characteristics dominate the chemical system with secondary salinity commonly occupying 40–70 per cent. Many Tensleep waters are marked by an exceptionally low bicarbonate content, a feature which ordinarily differentiates them from Embar water. Hydrogen sulphide commonly occurs in Tensleep water.

Madison water is generally marked by a somewhat higher secondary salinity than Tensleep water in the same area. In other respects it resembles Tensleep water; however, there are ordinarily sufficient differences to differentiate them in the same field. Hydrogen sulphide is present in most Madison waters.

APPENDIX

The primary objective of the water analyses made by the United States Geological Survey at its Midwest, Wyoming, field laboratory, is the identification of intrusive water in producing oil and gas wells. Identification of this water by chemical analysis has often effected considerable saving in time and money for oil and gas operators by identifying the zone from which the water comes.

The appended table has been prepared as an aid in identifying the various waters likely to be encountered in the oil and gas fields of the state. Those fields in which two or more different formation waters have been analyzed and definitely correlated with known geologic horizons are listed in the table with typical analyses of all formation waters sampled.

In line with the discussions in this paper, the fields have been arranged from north to south and west to east in the basins in which they occur, beginning with the Big Horn Basin, and concluding with the fields in the northeastern part of the state.

APPENDIX

BIG HORN BASIN

Field and Location	Formations									
	Surface Formation	*Shannon Sandstone Member of Steele Shale*	*Frontier Formation*	*"Dakota Group"*	*Sundance Formation*	*Embar Formation*	*Tensleep Sandstone*	*Madison Limestone*	*Miscellaneous*	*Remarks*
ELK BASIN T. 58 N.—R. 99 W.	*Eagle sandstone* Na 1,303 Ca 40 Mg 20 SO_4 1,963 Cl 80 HCO_3 1,049 T.S. 3,922	Not recognized	Na 3,980 Ca 28 Mg Tr SO_4 Tr Cl 5,300 HCO_3 1,525 T.S. 10,058	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled		
FRANNIE T. 58 N.—R. 98 W.		Not recognized	Outcrops	*Greybull* Na 419 Ca Tr Mg 0 SO_4 329 Cl 43 HCO_3 533 T.S. 1,114	Not sampled	Not sampled	Na 384 Ca 564 Mg 197 SO_4 2,159 Cl 90 HCO_3 825 T.S. 3,800	Not sampled		H_2S present in Tensleep water
BYRON T. 56 N.—R. 97 W.		Not recognized	Not sampled	Not sampled	Not sampled	Na 1,174 Ca 41 Mg 0 SO_4 1,869 Cl 305 HCO_3 340 T.S. 3,556	Na 45 Ca 715 Mg 161 SO_4 1,641 Cl 9 HCO_3 1,005 T.S. 3,065	Not sampled	*Chugwater* Na 9,766 Ca 209 Mg 222 SO_4 10,889 Cl 7,280 HCO_3 1,310 T.S. 29,010	H_2S present in Tensleep water
GARLAND T. 55 N.—R. 97 W.		Not recognized	Na 4,575 Ca 0 Mg 0 SO_4 0 Cl 2,305 HCO_3 8,180 T.S. 10,901	Not sampled	Not sampled	Not sampled	Not sampled	Na 290 Ca 801 Mg 136 SO_4 1,524 Cl 426 HCO_3 230 T.S. 2,960		H_2S present in Madison water

OREGON BASIN T. 51 N.—R. 100 W.		Not recognized	Na 701 Ca 0 Mg 0 SO_4 0 Cl 488 HCO_3 1,015 T.S. 1,688	Not sampled	Not sampled	Na 1,323 Ca 498 Mg 170 SO_4 2,959 Cl 350 HCO_3 1,520 T.S. 6,047	Not sampled	Not sampled	*Chugwater* Na 14,280 Ca 646 Mg 187 SO_4 10,472 Cl 15,850 HCO_3 135 T.S. 41,501
TORCHLIGHT T. 51 N.—R. 93 W.		Not recognized	Not sampled	*Greybull* Na 851 Ca 0 Mg 0 SO_4 823 Cl 88 HCO_3 1,065 T.S. 2,284	Not sampled	Not sampled	Not sampled	Na 54 Ca 46 Mg 0 SO_4 47 Cl 4 HCO_3 215 T.S. 257	
PAINTROCK T. 49 N.—R. 90 W.		Not recognized	Not sampled	Not sampled	Not sampled	Not sampled	Na 163 Ca 135 Mg 53 SO_4 720 Cl 11 HCO_3 175 T.S. 1,168	Na 163 Ca 377 Mg 0 SO_4 1,100 Cl 4 HCO_3 176 T.S. 1,731	
SKELTON DOME T. 45 N.—R. 100 W.		Not recognized	Na 577 Ca 32 Mg Tr SO_4 12 Cl 100 HCO_3 1,445 T.S. 1,430	*Greybull* Na 430 Ca 24 Mg Tr SO_4 350 Cl 35 HCO_3 710 T.S. 1,179	Not sampled	Not sampled	Not sampled	Not sampled	
TENSLEEP T. 46 N.—R. 89 W.		Not recognized	Not sampled	Not sampled	Not sampled	Not sampled	Na 267 Ca 776 Mg 56 SO_4 2,510 Cl 60 HCO_3 60 T.S. 3,698	Not sampled	*Amsden* Na 75 Ca 91 Mg Tr SO_4 133 Cl 83 HCO_3 167 T.S. 461

APPENDIX (continued)

Field and Location	Formations									
	Surface Formation	*Shannon Sandstone Member of Steele Shale*	*Frontier Formation*	*"Dakota Group"*	*Sundance Formation*	*Embar Formation*	*Tensleep Sandstone*	*Madison Limestone*	*Miscellaneous*	*Remarks*
NEIBER DOME T. 45 N.—R. 92 W.	*Fort Union* Na 531 Ca 24 Mg 0 SO_4 743 Cl 83 HCO_3 395 T.S. 1,637	Not recognized	Na 1,105 Ca 0 Mg 0 SO_4 244 Cl 551 HCO_3 1,675 T.S. 2,724	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled		
HAMILTON DOME T. 44 N.—R. 98 W.	*Mowry* Na 4,110 Ca 0 Mg 0 SO_4 3,395 Cl 47 HCO_3 1,000 T.S. 8,073	Not recognized	Not sampled	*Cloverly* Na 1,013 Ca 0 Mg 0 SO_4 826 Cl 133 HCO_3 1,410 T.S. 2,665	Not sampled	Na 3,673 Ca 338 Mg 75 SO_4 4,159 Cl 2,970 HCO_3 760 T.S. 11,588	Not sampled	Not sampled	*Chugwater* Na 15,349 Ca 696 Mg 81 SO_4 12,413 Cl 15,810 HCO_3 285 T.S. 44,489	
WAUGH DOME T. 44 N.—R. 97 W.		Not recognized	Not sampled	Not sampled	Not sampled	Na 905 Ca 173 Mg 65 SO_4 1,376 Cl 340 HCO_3 915 T.S. 3,309	Na 742 Ca 50 Mg 13 SO_4 1,099 Cl 410 HCO_3 80 T.S. 2,353	Not sampled		
BLACK MOUNTAIN T. 43 N.—R. 91 W.		Not recognized	Not sampled	Not sampled	Not sampled	Na 427 Ca 582 Mg 154 SO_4 2,176 Cl 78 HCO_3 781 T.S. 3,802	Na 74 Ca 76 Mg 16 SO_4 44 Cl 16 HCO_3 425 T.S. 435	Not sampled		H_2S present in both Embar and Tensleep waters

	WIND RIVER BASIN								
PILOT BUTTE T. 3 N.—R. 1 W.		*Steele shale* Na 2,796 Ca 16 Mg 35 SO_4 0 Cl 3,400 HCO_3 1,795 T.S. 7,100	Na 1,698 Ca 24 Mg 57 SO_4 0 Cl 1,395 HCO_3 2,472 T.S. 4,383	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled		
LANDER T. 2 S.—R. 2 E.		Not recognized	Not sampled	Not sampled	Not sampled	Na 117 Ca 109 Mg 28 SO_4 256 Cl 38 HCO_3 390 T.S. 740	Na 34 Ca 48 Mg 12 SO_4 60 Cl 6 HCO_3 190 T.S. 247	Not sampled		H_2S present in both Embar and Tensleep waters
DERBY DOME T. 31 N.—R. 98 W.		Not recognized	Not sampled	Not sampled	Not sampled	Na 373 Ca 220 Mg 43 SO_4 1,178 Cl 12 HCO_3 355 T.S. 2,001	Na 4 Ca 35 Mg 22 SO_4 22 Cl 3 HCO_3 195 T.S. 182	Not sampled		H_2S present in both Embar and Tensleep waters
ALKALI BUTTE T. 33 N.—R. 95 W.	*Mesaverde* Na 120 Ca 317 Mg 284 SO_4 1,560 Cl 36 HCO_3 665 T.S. 2,644	*Steele shale* Na 2,805 Ca 0 Mg 0 SO_4 0 Cl 3,518 HCO_3 1,390 T.S. 7,007	Na 2,438 Ca 0 Mg 0 SO_4 19 Cl 2,609 HCO_3 2,000 T.S. 6,028	*Muddy* Na 4,645 Ca 0 Mg 0 SO_4 705 Cl 4,682 HCO_3 3,065 T.S. 11,719	Not sampled	Not sampled	Not sampled	Not sampled		

APPENDIX (continued)

Field and Location	Formations									
	Surface Formation	*Shannon Sandstone Member of Steele Shale*	*Frontier Formation*	*"Dakota Group"*	*Sundance Formation*	*Embar Formation*	*Tensleep Sandstone*	*Madison Limestone*	*Miscellaneous*	*Remarks*
SWEETWATER BASIN										
NORTH BAXTER BASIN T. 19 N.—R. 104 W.		Not recognized	Na 10,879 Ca 222 Mg 125 SO_4 0 Cl 16,667 HCO_3 1,490 T.S. 28,626	*Dakota* Na 6,546 Ca 164 Mg 81 SO_4 306 Cl 9,800 HCO_3 1,025 T.S. 17,401	*Upper Sundance* Na 6,082 Ca 62 Mg 31 SO_4 1,737 Cl 6,240 HCO_3 3,540 T.S. 15,893 *Second Sundance* Na 5,288 Ca 23 Mg Tr SO_4 151 Cl 3,900 HCO_3 7,200 T.S. 12,902 *Third Sundance* Na 3,729 Ca 122 Mg Tr SO_4 0 Cl 3,744 HCO_3 3,825 T.S. 9,476	Not sampled	Not sampled	Not sampled		H_2S present in Third Sundance water
MIDDLE BAXTER BASIN T. 18 N.—R. 103 W.		Not recognized	Na 12,856 Ca 48 Mg 57 SO_4 41 Cl 15,652 HCO_3 7,450 T.S. 32,318	*Dakota* Na 6,456 Ca 0 Mg 0 SO_4 23 Cl 5,928 HCO_3 6,900 T.S. 15,799	Not sampled	Not sampled	Not sampled	Not sampled		

South Baxter Basin T. 17 N.—R. 104 W.		Not recognized	Na 8,790 Ca 0 Mg 0 SO_4 0 Cl 8,150 HCO_3 9,250 T.S. 21,515	*Dakota* Na 4,093 Ca 56 Mg 33 SO_4 0 Cl 4,032 HCO_3 4,260 T.S. 10,309	Na 3,162 Ca 12 Mg Tr SO_4 153 Cl 3,250 HCO_3 2,640 T.S. 7,876	Not sampled	Not sampled	Not sampled		H_2S present in Sundance water
Sheep Creek T. 28 N.—R 92 W.		Not recognized	Not sampled	Not sampled	Na 64 Ca 50 Mg 34 SO_4 165 Cl 36 HCO_3 220 T.S. 457	Na 1,198 Ca 503 Mg 195 SO_4 2,963 Cl 335 HCO_3 1,340 T.S. 5,853	Not sampled	Not sampled		H_2S present in Embar water
Lost Soldier T. 26 N.—R. 90 W.		Not recognized	Na 5,376 Ca 36 Mg Tr SO_4 0 Cl 5,100 HCO_3 5,595 T.S. 13,263	*Basal Cloverly* Na 2,219 Ca 32 Mg 20 SO_4 265 Cl 1,300 HCO_3 3,510 T.S. 5,436	Na 1,786 Ca 0 Mg 0 SO_4 0 Cl 1,051 HCO_3 2,930 T.S. 4,278	Not sampled	Not sampled	Not sampled		
Eight Mile Lake T. 19 N.—R. 88 W.		Not recognized	Na 522 Ca 0 Mg 0 SO_4 Tr Cl 49 HCO_3 1,300 T.S. 1,209	*Upper Cloverly* Na 1,943 Ca 26 Mg 3 SO_4 50 Cl 2,000 HCO_3 1,745 T.S. 4,872	Not sampled	Not sampled	Not sampled	Not sampled		

APPENDIX (continued)

Field and Location	Formations										Remarks
	Surface Formation	*Shannon Sandstone Member of Steele Shale*	*Frontier Formation*	*"Dakota Group"*	*Sundance Formation*	*Embar Formation*	*Tensleep Sandstone*	*Madison Limestone*	*Miscellaneous*		
LARAMIE BASIN											
MEDICINE BOW T. 21 N.—R. 79 W.		Not sampled	Not sampled	Not sampled	Na 663 Ca 0 Mg 0 SO_4 477 Cl 157 HCO_3 880 T.S. 1,729	Not sampled	Na 605 Ca 475 Mg 63 SO_4 2,024 Cl 385 HCO_3 135 T.S. 3,618	Not sampled	*Mesaverde* Na 170 Ca 57 Mg 30 SO_4 389 Cl 11 HCO_3 263 T.S. 786		
ROCK CREEK T. 19 N.—R. 78 W.		Not sampled	Not sampled	*Cloverly* Na 6,207 Ca 0 Mg 0 SO_4 0 Cl 9,072 HCO_3 868 T.S. 15,702	Na 918 Ca 0 Mg 0 SO_4 319 Cl 227 HCO_3 1,650 T.S. 2,274	Not sampled	Not sampled	Not sampled			
BIG HOLLOW T. 16 N.—R. 74 W.		Not sampled	Not sampled	*Upper Cloverly* Na 378 Ca 0 Mg 0 SO_4 184 Cl 171 HCO_3 475 T.S. 967	Not sampled	Not sampled	Na 785 Ca 205 Mg 11 SO_4 1,881 Cl 135 HCO_3 135 T.S. 3,083	Not sampled			
POISON SPIDER AREA											
NOTCHES T. 37 N.—R. 85 W.		Not sampled	Not sampled	*Dakota(?)* Na 475 Ca 20 Mg 34 SO_4 727 Cl 14 HCO_3 540 T.S. 1,536	Not sampled	Not sampled	Na 425 Ca 264 Mg 58 SO_4 900 Cl 281 HCO_3 638 T.S. 2,244	Not sampled			H_2S present in Tensleep water

South Casper Creek T. 33 N.—R. 83 W.		Not sampled	Not sampled	Not sampled	Na 1,096 Ca 44 Mg Tr SO_4 528 Cl 775 HCO_3 1,040 T.S. 2,081	Not sampled	Na 356 Ca 493 Mg 103 SO_4 1,752 Cl 345 HCO_3 145 T.S. 3,120	Not sampled		H_2S present in Tensleep water
Poison Spider T. 33 N.—R. 82 W.		Not sampled	Not sampled	*Dakota(?)* Na 349 Ca 6 Mg 0 SO_4 325 Cl 15 HCO_3 510 T.S. 944	Na 700 Ca 6 Mg 14 SO_4 99 Cl 25 HCO_3 1,820 T.S. 1,519	Not sampled	Not sampled	Not sampled		
Spindletop T. 30 N.—R. 81 W.		Not sampled	Not sampled	*Dakota(?)* Na 413 Ca 18 Mg 4 SO_4 520 Cl 40 HCO_3 440 T.S 1,205	Na 790 Ca 0 Mg 0 SO_4 762 Cl 127 HCO_3 910 T.S. 2,126	Not sampled	Not sampled	Not sampled		
Bolton Creek T. 29 N.—R. 81 W.		Not sampled	Not sampled	*Dakota(?)* Na 226 Ca 0 Mg 0 SO_4 143 Cl 32 HCO_3 365 T.S. 579	Na 664 Ca 0 Mg 0 SO_4 595 Cl 140 HCO_3 763 T.S. 1,774	Not sampled	Not sampled	Not sampled		
Powder River Basin										
Tisdale T. 41 N.—R. 81 W.		Not sampled	Not sampled	Not sampled	Na 5,035 Ca 560 Mg 157 SO_4 2,375 Cl 7,409 HCO_3 68 T.S. 15,568	Not sampled	Na 516 Ca 231 Mg 85 SO_4 1,057 Cl 605 HCO_3 115 T.S. 2,551	Not sampled	*Amsden* Na 468 Ca 80 Mg 114 SO_4 484 Cl 742 HCO_3 154 T.S. 1,964	H_2S present in Tensleep water

APPENDIX (continued)

Field and Location	Formations									Remarks
	Surface Formation	*Shannon Sandstone Member of Steele Shale*	*Frontier Formation*	*"Dakota Group"*	*Sundance Formation*	*Embar Formation*	*Tensleep Sandstone*	*Madison Limestone*	*Miscellaneous*	
POWDER RIVER BASIN (continued)										
			1st Wall Creek Na 1,143 Ca Tr Mg 0 SO_4 Tr Cl 840 HCO_3 1,585 T.S. 2,762	*Dakota* Na 5,131 Ca 38 Mg 6 SO_4 42 Cl 6,850 HCO_3 1,915 T.S. 13,009	*Second Sand* Na 3,827 Ca 24 Mg 12 SO_4 90 Cl 4,850 HCO_3 1,220 T.S. 9,483					
SALT CREEK T. 40 N.—R. 79 W.		Na 851 Ca 172 Mg 263 SO_4 2,272 Cl 29 HCO_3 1,160 T.S. 4,157	*2nd Wall Creek* Na 4,680 Ca 0 Mg 0 SO_4 0 Cl 5,534 HCO_3 2,900 T.S. 11,638	*Upper Lakota* Na 2,008 Ca 0 Mg 0 SO_4 0 Cl 1,928 HCO_3 2,015 T.S. 4,925	*Third Sand* Na 4,009 Ca 334 Mg 59 SO_4 2,662 Cl 4,568 HCO_3 710 T.S. 11,981	Not sampled	Na 456 Ca 378 Mg 82 SO_4 1,231 Cl 604 HCO_3 170 T.S. 2,836	Not sampled		H_2S present in Third Sundance water
			3rd Wall Creek Na 5,942 Ca 0 Mg 0 SO_4 0 Cl 7,564 HCO_3 2,760 T.S. 14,863	*Lower Lakota* Na 1,035 Ca Tr Mg 0 SO_4 Tr Cl 650 HCO_3 1,625 T.S. 2,484						
MIDWAY T. 35 N.—R. 79 W.		Not sampled	Na 2,568 Ca 21 Mg Tr SO_4 113 Cl 2,850 HCO_3 1,830 T.S. 6,452	*Lakota* Na 1,114 Ca 8 Mg 0 SO_4 521 Cl 107 HCO_3 2,160 T.S. 2,805	Not sampled	Not sampled	Not sampled	Not sampled		
COLE CREEK T. 35 N.—R. 77 W.		Not sampled	Na 6,946 Ca 0 Mg 0 SO_4 107 Cl 9,360 HCO_3 2,200 T.S. 17,490	*Lakota* Na 2,280 Ca 67 Mg 0 SO_4 1,321 Cl 2,080 HCO_3 995 T.S. 6,237	Not sampled	Not sampled	Not sampled	Not sampled		

BIG MUDDY T. 33 N.—R. 76 W.		Na 5,044 Ca 78 Mg 38 SO_4 0 Cl 7,668 HCO_3 620 T.S. 13,133	Na 2,976 Ca 0 Mg 0 SO_4 0 Cl 1,976 HCO_3 4,505 T.S. 7,167	*Lakota* Na 1,318 Ca 0 Mg 0 SO_4 485 Cl 616 HCO_3 1,800 T.S. 3,310	Na 1,492 Ca 0 Mg 0 SO_4 1,330 Cl 686 HCO_3 1,095 T.S. 4,044	Not sampled	Not sampled	Not sampled	
LANCE CREEK T. 35 N.—R. 65 W.		Not sampled	Not sampled	*First Fall River* Na 834 Ca 0 Mg 0 SO_4 0 Cl 52 HCO_3 2,125 T.S. 1,931 *Second Fall River* Na 731 Ca 0 Mg 0 SO_4 86 Cl 252 HCO_3 1,400 T.S. 1,756	Na 1,892 Ca 101 Mg 26 SO_4 3,138 Cl 473 HCO_3 660 T.S. 5,955	Not sampled	*Converse* Na 240 Ca 465 Mg 68 SO_4 1,684 Cl 73 HCO_3 130 T.S. 2,594 *Leo* Na 589 Ca 317 Mg 75 SO_4 1,415 Cl 563 HCO_3 138 T.S. 3,027	Not sampled	
OSAGE T. 46 N.—R. 63 W.		Not sampled	Not sampled	*Lakota* Na 257 Ca 0 Mg 0 SO_4 355 Cl 8 HCO_3 215 T.S. 780	Not sampled	Not sampled	Not sampled	Not sampled	*Greenhorn* Na 5,899 Ca 45 Mg 21 SO_4 64 Cl 8,785 HCO_3 700 T.S. 15,158
WEST MULE CREEK T. 40 N.—R. 61 W.		Not sampled	Not sampled	*Fall River* Na 338 Ca 0 Mg 0 SO_4 233 Cl 44 HCO_3 433 T.S. 795	Na 1,397 Ca 290 Mg 110 SO_4 3,898 Cl 47 HCO_3 110 T.S. 5,796	Not sampled	*Minnelusa* Na 714 Ca 536 Mg 178 SO_4 3,362 Cl 55 HCO_3 56 T.S. 4,873	Not sampled	
ANT HILLS T 37 N.—R. 63 W.		Not sampled	Not sampled	*Fall River* Na 520 Ca 15 Mg 7 SO_4 50 Cl 350 HCO_3 795 T.S. 1,343	Not sampled	Not sampled	*Minnelusa* Na 1,272 Ca 450 Mg 57 SO_4 2,923 Cl 624 HCO_3 245 T.S. 5,447	Not sampled	

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GEOLOGICAL NOTES

RIO BRAVO OIL FIELD, KERN COUNTY, CALIFORNIA[1]

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The Rio Bravo field, 15 miles northwest of Bakersfield, Kern County, California, was the third in a series of oil fields discovered as a result of reflection-seismograph work in the relatively flat alluvium-covered part of the San Joaquin Valley. The discovery well, the Union Oil Company's Kernco No. 1-34 (now designated 85-34), was spudded, March 29, 1937. The top of the Rio Bravo sand was encountered at 11,240 feet and the well completed November 4, 1937, at a total depth of 11,302 feet, flowing 38.7° gravity oil at the rate of 2,400 barrels per day through a 40/64-inch bean with a pressure of 1,500 pounds on the tubing and 1,700 pounds on the casing. The oil was clean, cutting less than 0.1 per cent and was accompanied by a flow of gas estimated at 2 million cubic feet.

The first few wells completed in the field took only the limited penetration of the discovery well. The Superior Oil Company's Ruhl No. 1 was the first to drill through the grit zone into the lower sand. Since then, it has been general practice to complete the wells with both sands open.[3] Penetration into the oil sand has varied throughout the field from 21 feet in the Superior Oil Company's Moody No. 1 to 325 feet in the Superior's Wagner No. 3. Average penetration of the favorably located wells is 275 feet, of which approximately 240 feet is oil sand. Average porosity of the sand is about 20 per cent. The permeability is variable but averages close to 450 millidarcys for the better part of the field. There are now 40 wells producing, one abandoned, and four drilling. All wells are producing under strict curtailment, with the daily production of the field averaging about 7,100 barrels. Total production of the field to February 1, 1940, is 5,187,795 barrels.

Rio Bravo was the first field in the state to produce from sands

[1] This paper was prepared to form a part of *Bulletin 118*, "Geologic Formations and Economic Development of the Oil and Gas Fields of California" (now in press), prepared under the direction of Olaf P. Jenkins, chief geologist, Geologic Branch, California State Division of Mines. It is reproduced herewith through the courtesy and permission of Walter W. Bradley, State mineralogist. Manuscript received, May 27, 1940.

[2] Union Oil Company.

[3] In the field, the part of the Rio Bravo zone above the grit is commonly referred to as the "Rio Bravo sand" and the part below as the "Vedder sand."

below 11,000 feet, and for a while the discovery well was the deepest commercially productive oil well in the world. The action of these wells has demonstrated conclusively that depth is not necessarily an unfavorable factor. Although the wells are all producing from below 11,000 feet, their cost is not excessive because of the ease and speed with which they can be drilled. Most of the recently drilled wells have been completed in 45–60 days. Heavier equipment, improvements in drilling technique, and careful control of the drilling fluid have made this possible. Very little coring is done and most of the correlating is done with electric logs. Some operators drill into the oil sand before setting casing, while others prefer to drill to within a few feet of the estimated top of the sand, check their position by one or two cores or an electric log and then set casing before entering the sand.

The general drilling program is to cement 13⅜-inch casing at 1,500–2,000 feet, drill with 12¼-inch bits to approximately 8,500 feet, reduce hole and drill with 11¾-inch bits to 10,000 feet, then reduce hole to 11 inches and drill to or near the top of the Rio Bravo sand. Seven-inch casing is cemented over the sand at approximately 11,200 feet, and the well completed at about 11,475 feet with 5-inch or 5½-inch perforated liner. A few of the wells have been completed satisfactorily without the use of a liner.

Accumulation is apparently controlled by a northwest-southeast trending anticline having a closure in excess of 300 feet. At present the productive area covers about 900 acres but it is evident that future development will substantially extend the present limits of the field. The Superior Oil Company's Roe No. 1 topped the oil sand at 11,159 feet and at this date, February 15, 1940, it is the farthest northwest and also the highest well in the field.

There has been some evidence to suggest the possibility of a fault along the northeast side of the field (possibly of the rift type) but whether this flank is bounded by a fault or a relatively sharp syncline can not be determined until additional wells are drilled.

The formations encountered in drilling are shown on the generalized stratigraphic column accompanying the contour map of the field (Fig. 1). It is interesting to note that the Greeley sand productive in the Greeley field on the southeast is not present at Rio Bravo as a sand. The interval cored in the discovery well from 8,463 to 8,690 feet is probably the equivalent of the Greeley zone and except for about 1½ feet of silty oil sand, it is made up entirely of hard brown shale. To the present time, Schlumberger logs have not indicated the presence of the Greeley sand anywhere in the field.

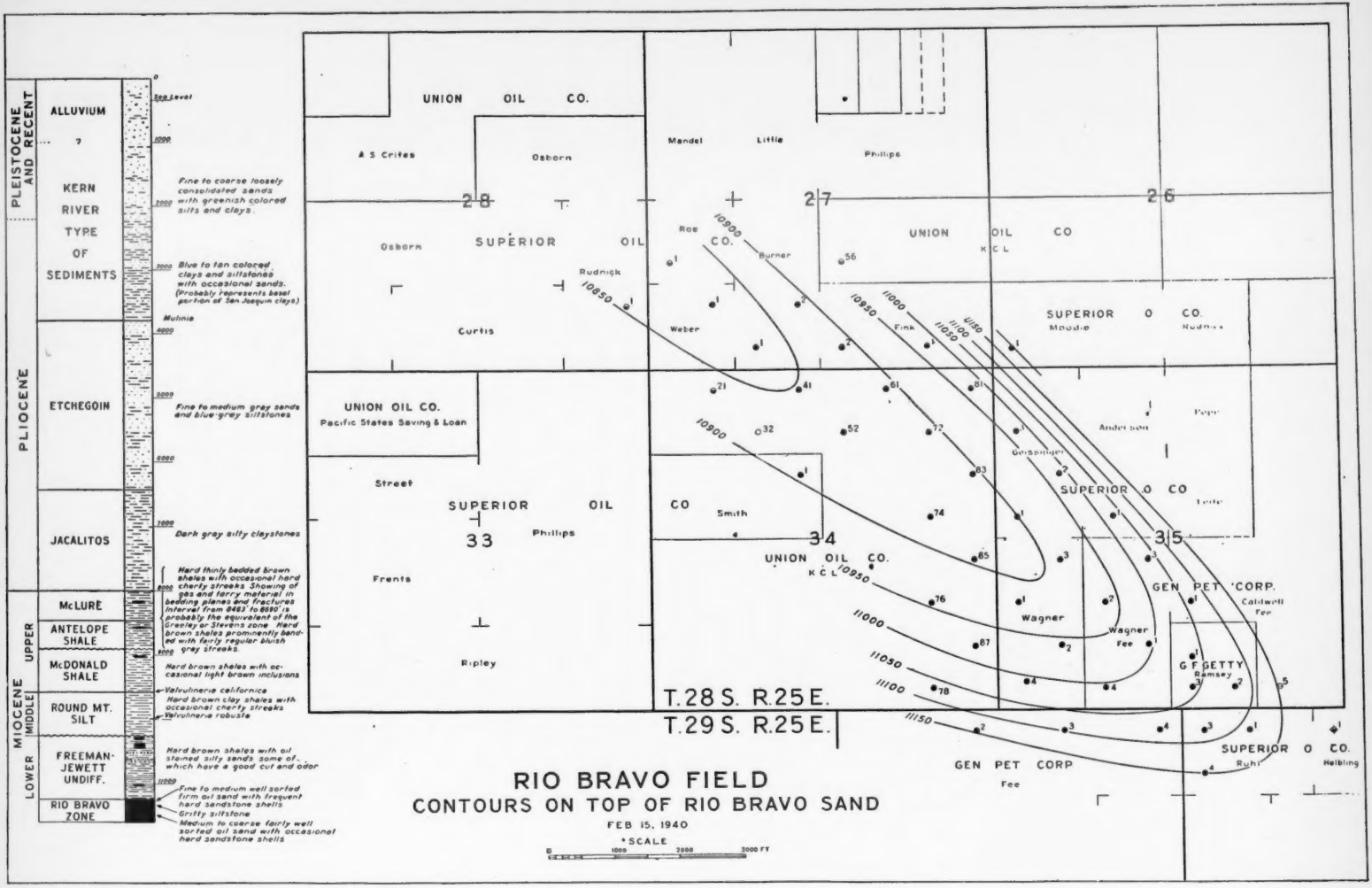
PLEISTOCENE AND RECENT
PLIOCENE
MIOCENE
UPPER
MIDDLE
LOWER
ALLUVIUM
?
KERN RIVER TYPE OF SEDIMENTS
ETCHEGOIN
JACALITOS
McLURE
ANTELOPE SHALE
McDONALD SHALE
ROUND MT. SILT
FREEMAN-JEWETT UNDIFF.
RIO BRAVO ZONE
Fine to coarse loosely consolidated sands with greenish colored silts and clays.
Blue to tan colored clays and siltstones with occasional sands. (Probably represents basal portion of San Joaquin clays)
Fine to medium grey sands and blue-grey siltstones
Dark grey silty claystones
Hard thinly bedded brown shales with occasional hard cherty streaks. Showing of gas and tarry material in bedding planes and fractures. Interval from 8463' to 8690' is probably the equivalent of the Greeley or Stevens zone. Hard brown shales prominently banded with fairly regular bluish grey streaks.
Hard brown shales with occasional light brown inclusions
Valvulineria californica
Hard brown clay shales with occasional cherty streaks
Valvulineria robusta
Hard brown shales with oil stained silty sands some of which have a good cut and odor
Fine to medium well sorted firm oil sand with frequent hard sandstone shells
Gritty siltstone
Medium to coarse fairly well sorted oil sand with occasional hard sandstone shells
UNION OIL CO.
A S Crites
Osborn
28
SUPERIOR OIL CO.
Osborn
Curtis
Rudnick
Weber
Roe
Burner
Mendel
Little
Phillips
27
26
UNION OIL CO
SUPERIOR O CO.
Moodie
Rudnick
UNION OIL CO.
Pacific States Saving & Loan
Street
SUPERIOR OIL CO
Smith
33
Phillips
Frents
Ripley
34
UNION OIL CO.
Anderson
Gerspringer
SUPERIOR O CO
35
GEN PET CORP.
Caldwell Fee
Wagner
Wagner Fee
G F GETTY
Ramsey
GEN PET CORP
Fee
SUPERIOR O CO.
Helbing
10900
10850
11000
10950
11050
11100
11150
T.28 S. R.25E.
T.29 S. R.25E.
RIO BRAVO FIELD
CONTOURS ON TOP OF RIO BRAVO SAND
FEB 15, 1940
SCALE
1000
2000
3000 FT

FIG. 1

Only one well, the Superior Oil Company's Helbling No. 1, has been drilled below the present producing zone. This well encountered a fault at about 10,000 feet and apparently was in a fault zone for the next 2,000–3,000 feet, as many of the cores showed slickensiding, brecciation, and erratic dips. The lower part of the hole was logged as hard brown to gray shales and hard medium to fine sandstones. The well was abandoned at 14,018 feet in what is generally believed to be basement rock.

The field is characterized by having only one producing zone and this entirely below 11,000 feet. Many of the wells, if opened, could produce more than 10,000 barrels per day. No attempt has ever been made to establish a potential and all producers as completed are assigned an assumed potential of 6,000 barrels per day, and immediately restricted to conform to the field allowable which at present is 185 barrels per day per well. The wells produce with a low gas-oil ratio, averaging about 1,100 cubic feet per barrel.

Bottom-hole pressure is about 4,675 pounds per square inch and to date there has been no substantial decline in pressure. Bottom-hole temperature is approximately 250°F. No reliable estimate of future production from the Rio Bravo zone can be made at this time but present available data indicate an ultimate recovery of about 340 barrels per acre foot. The oil ranges in gravity from 36° to 41°, has about 46 per cent of 425° end-point gasoline, 33 per cent of 725° end-point gas oil, and 20 per cent residuum. The sulphur content varies from 0.2 to 0.4 per cent. Knock rating varies from 56 to 61. The oil has the general characteristics of a waxy base oil similar to that in Kettleman Hills and deep zones at Santa Fe Springs.

STRAND OIL FIELD, KERN COUNTY, CALIFORNIA[1]

F. A. MENKEN[2]
San Francisco, California

Among California discoveries of 1939 is the Strand field in the south-central San Joaquin Valley. This new field is 12 miles southwest of Bakersfield, 3 miles north of the Ten Section field, and ½ mile northeast of the Canal field. Its geographic location with respect to these two fields and other mid-valley fields is shown on Figure 1.

[1] Read before the Pacific Section of the Association at Los Angeles, November 10, 1939. A similar paper was prepared to form a part of *Bulletin 118*, "Geologic Formations and Economic Development of the Oil and Gas Fields of California" (now in press), of the Geologic Branch, California State Division of Mines. Manuscript received, May 27, 1940.

[2] Chief geologist, Tide Water Associated Oil Company, Associated Division.

The discovery well, the Tide Water Associated Oil Company's Continental Oil Company KCL E-35-7, near the center of Sec. 7, T. 30 S., R. 26 E., M.D.B. & M., Kern County, was completed on June 12, 1939. This well was completed at a depth of 8,364 feet. The

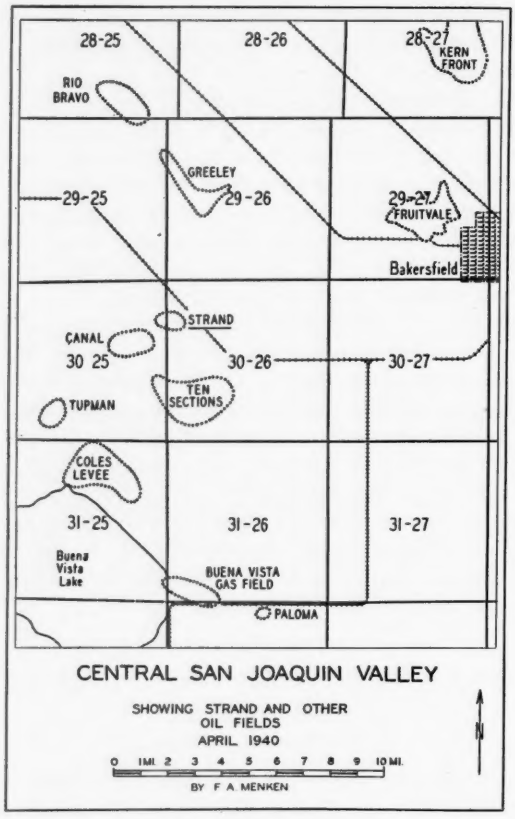

FIG. 1

top of the oil sand was encountered at 8,305 feet. Initial production was 1,300 barrels per day of 34.0° gravity oil, cutting 3.3 per cent emulsion, with 980,000 cubic feet of gas through one 48/64-inch bean, tubing pressure of 100 pounds, and casing pressure of 800 pounds.

On April 1, 1940, there were 8 wells producing, 2 drilling, and one preparing to spud in. Wells are generally completed in a total elapsed

time of 32–36 days from spudding to completion. The average completion is at a depth of 8,350 feet with 7-inch casing cemented at approximately 8,250–8,300 feet with a 5-inch liner perforated 100-mesh. Completions range from 600 barrels per day to 3,600 barrels per day of 34° gravity oil with gas-oil ratios varying from 500 to 1,000 cubic feet per barrel; flow pressures are 700–800 pounds on the tubing and 800–1,600 pounds on the casing. The bottom-hole pressure is 3,600 pounds. Under curtailment the daily production from the 8 wells is 1,449 barrels, the potential being 18,370 barrels per day. The cumulative production on April 1, 1940, was 254,300 barrels.

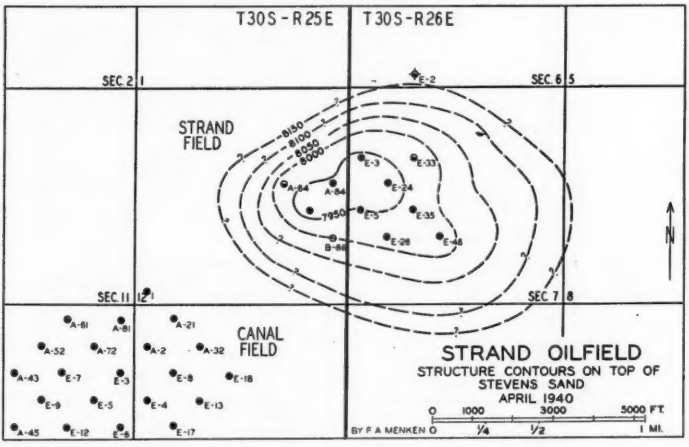

FIG. 2

Detailed reflection-seismograph work and regional subsurface studies resulted in this discovery. The mapping of the critical closure required very close spacing of shot points and a program of small closed seismograph traverses. Reflection correlation was also of aid in confirming the structure mapped by dip shooting and continuous profiling.

The Strand field is an east-west trending anticlinal dome, having a structural relief of approximately 300 feet in the producing measures. It is a fold thought not to be directly related to either the Wasco-Greeley trend or the Buttonwillow-Ten Section trend, although it is only a short distance from the latter and may, from future subsurface control, be found to be *en échelon* to the principal line of uplift. A structure contour map of the field is shown on Figure 2.

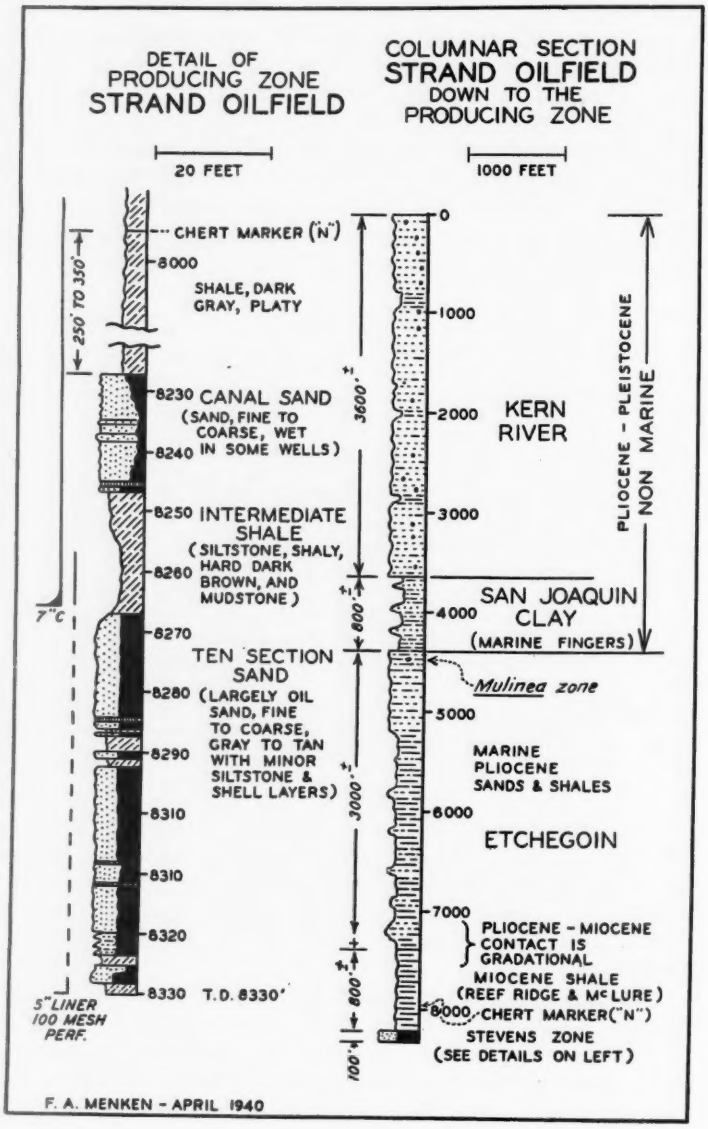
DETAIL OF PRODUCING ZONE STRAND OILFIELD
20 FEET
CHERT MARKER ("N")
8000
SHALE, DARK GRAY, PLATY
250' TO 350'
8230 CANAL SAND
(SAND, FINE TO COARSE, WET IN SOME WELLS)
8240
8250 INTERMEDIATE SHALE
(SILTSTONE, SHALY, HARD DARK BROWN, AND MUDSTONE)
8260
7"C
8270
TEN SECTION SAND
8280 (LARGELY OIL SAND, FINE TO COARSE, GRAY TO TAN WITH MINOR SILTSTONE & SHELL LAYERS)
8290
8310
8310
8320
8330 T.D. 8330'
5" LINER 100 MESH PERF.
3600'±
800'±
3000'±
800'±
100'±
COLUMNAR SECTION STRAND OILFIELD DOWN TO THE PRODUCING ZONE
1000 FEET
0
1000
2000
3000
4000
5000
6000
7000
8000
KERN RIVER
SAN JOAQUIN CLAY
(MARINE FINGERS)
Mulinea zone
MARINE PLIOCENE SANDS & SHALES
ETCHEGOIN
PLIOCENE - MIOCENE CONTACT IS GRADATIONAL
MIOCENE SHALE (REEF RIDGE & McLURE)
CHERT MARKER("N")
STEVENS ZONE
(SEE DETAILS ON LEFT)
PLIOCENE - PLEISTOCENE NON MARINE
F. A. MENKEN - APRIL 1940

FIG. 3

The productive sands are upper Miocene in age, equivalent to the Mohnian stage, and belong in the Stevens zone. Locally the main producing sand is known as the Ten Section sand, being tentatively correlated with the upper sand in the Ten Section field. A higher sand zone, having a thickness of 20–40 feet, has been found productive in a few wells. This upper sand is 15–25 feet above the Ten Section sand and has been tentatively correlated with the Canal sand of the Canal field. Figure 3 depicts the details of the productive interval in the Strand field and shows the relative position of the productive measures in the San Joaquin Valley upper Tertiary sections. The produc-

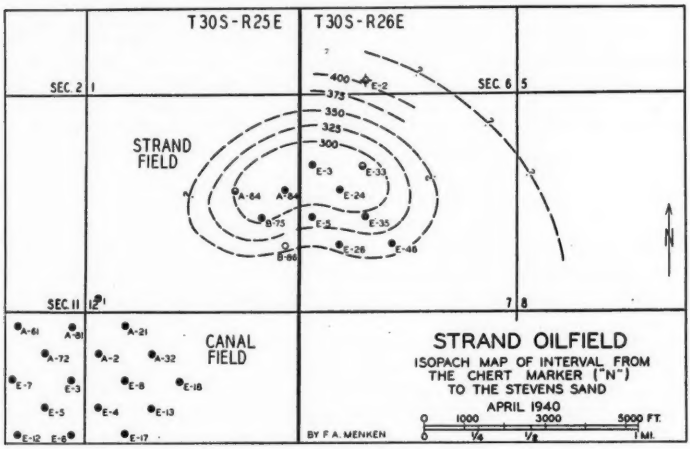

FIG. 4

tive Ten Section sand is massive, friable, medium to coarse, and poorly sorted. The average porosity of this sand is 26.3 per cent and the permeability ranges from 136 to 901 millidarcys, averaging 380 millidarcys.

Developments in the mid-valley fields of Kern County have demonstrated that sands in the upper Miocene are not continuous and do not in all cases represent stratigraphic equivalents, thus precluding the use of the top of sand for correlation purposes over wide areas. An electric log marker, ranging from 150 feet to 300 feet above the first sands and considered to be a stratigraphic marker, is used for correlation purposes. This marker is within the cherty or silicious upper Miocene shale and is referred to as the "N" point or chert marker. In the Strand field it has been found that the interval between the

chert marker and the oil sands, particularly the Ten Section sand, varies to a considerable degree, with the lesser interval near the apex of the structure. Figure 4 is an isopach map showing the variable intervals. It is significant that in effect this downward migration of the sand on the flanks results in a greater effective closure, a combination of structure and stratigraphy. This feature is thought to be in part the reason for the seismograph structure appearing smaller in closure and areal extent than that now indicated by well records.

The deepest well drilled to date in the Strand field, and located on the west plunge, penetrated 958 feet below the chert marker. The formations in the Stevens zone below the productive Ten Section sand were medium to fine friable sands with here and there interbedded siltstones or silty shales: The sands were, in part, oil-bearing and one lower sand on a formation test indicated commercial production. Production from deeper Miocene sands, known to be productive in some mid-valley fields, is still a possibility in the Strand field.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 7 (JULY, 1940): PP. 1339-1342

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available, for loan, to members and associates.

LECTURE NOTES ON PRACTICAL PETROLEUM GEOPHYSICS, BY GARRETT KEMP

REVIEW BY MICHEL T. HALBOUTY
Houston, Texas

"Lecture Notes on Practical Petroleum Geophysics," by Garrett Kemp. *Texas Agric. and Mechan. College Eng. Exp. Sta. Bull. 48* (1940). 66 pp., illus. Non-mathematical. College Station, Texas. Free.

A bulletin based on lecture notes on practical petroleum geophysics has been prepared by the Texas Agricultural and Mechanical College through the facilities made possible by the petroleum engineering department of the college. These lecture notes were compiled by Dr. Garrett Kemp who delivered a series of geophysical lectures at Texas A. & M. College in April, 1940.

The bulletin treats the subject of practical petroleum geophysics in a manner that should be interesting and instructive to those who are not experts, or very familiar with geophysical principles.

The lectures open with a discussion of the general principles and developments of geophysical methods and the fundamentals on which these principles are based. Such related subjects as isostasy, gravitation, and temperature gradients are well discussed.

The instruments used in present-day geophysical surveys by the oil industry are discussed very thoroughly with excellent illustrations as to the application of these instruments. Photographs, specimens of work obtained from each instrument, and the best method of field use are clearly illustrated for each instrument.

This bulletin is in reality an excellent outline for the possibility of a textbook on geophysics. The reader will find that many ideas can be obtained from it on practical petroleum geophysics.

RECENT PUBLICATIONS

ARKANSAS–LOUISIANA

**Upper and Lower Cretaceous of Southwest Arkansas, Supplemented by Contributions to the Surface Stratigraphy of South Arkansas and North Louisiana*, by the Shreveport Geological Society. Guide Book of Fourteenth Annual Field Trip, June 2–4, 1939. Second printing (July, 1940). 216 pp., 60 pp. of illustrations (stratigraphic sections, structure-contour maps, correlation tables, diagnostic fossils, folded cross sections, route maps, photographic views). Lithographed typewritten pages, 8.5×10.875 inches. "Plastic" binding. This is a reprint, without change, from the original printing. Address: E. Weldon Cartwright, secretary-treasurer, Shreveport Geological Society, 809 Giddens-Lane Building, Shreveport, Louisiana. Price, $3.00.

BRAZIL

*"Agua Subterrânea em Minas Gerais" (Subsurface Waters in Minas Gerais), by Octavio Barbosa. *Brasil Div. de Fomento da Prod. Mineral Avulso 43* (Rio de Janeiro, 1940). 40 pp., 9 figs., tables. In Portuguese.

**História da Pesquisa de Petróleo no Brasil* (History of the Search for Petroleum in Brazil), by Euzebio Paulo de Oliveira. Ministério de Agricultura, Rio de Janeiro (1940). 208 pp.

CALIFORNIA

*"Flood Gravels of San Gabriel Canyon, California," by W. C. Krumbein. *Bull. Geol. Soc. America*, Vol. 51, No. 5 (New York, May 1, 1940), pp. 639–76; 1 pl., 13 figs.

*"Sierra Nevada Tectonic Pattern," by Augustus Locke, Paul Billingsley, and Evans B. Mayo. *Ibid.*, No. 4 (April, 1940), pp. 513–40; 2 pls., 1 fig.

*"Drilling-In with Oil in Kettleman Hills Oil Field," by F. C. Hodges. *Summary of Operations, California Oil Fields* (San Francisco), Vol. 23, No. 4 (April, May, June, 1938; issued, May, 1940), pp. 5–11; 1 table.

*"The Development of Micropaleontology in California," by Hubert G. Schenck, A. Myra Keen, and Lois T. Martin. *Oil and Gas Jour.* (Tulsa), Vol. 39, No. 2 (May 23, 1940), pp. 40–41; 1 table, 1 fig.

CANADA

*"Lower and Middle Cambrian Stratigraphy of Southwestern Alberta and Southeastern British Columbia," by Charles Deiss. *Bull. Geol. Soc. America*, Vol. 51, No. 5 (New York, May 1, 1940), pp. 731–94; 5 pls., 6 figs.

COLORADO

*"Lime-Secreting Algae and Algal Limestones from the Pennsylvanian of Central Colorado," by J. Harlan Johnson. *Bull. Geol. Soc. America* (New York), Vol. 51, No. 4 (April 1, 1940), pp. 571–96; 10 pls., 4 figs.

FRANCE

*"Le Pétrole en France" (Petroleum in France), *Anon. La Rev. Pétrolifère*, No. 885 (Paris, May 4, 1940), pp. 268–70; 2 maps.

GENERAL

*"Die Petrographie der sandigen Sedimente in ihre Bedeutung für die Erdölgeologie" (Petrography of Sandy Sediments in Their Importance for Petroleum Geology), by Wolfgang Richter. *Oel und Kohle mit Petroleum* (Berlin), Vol. 36, No. 17 (May 1, 1940), pp. 150–58; 6 figs.

*"Submarine Valleys and Related Geologic Problems of the North Atlantic," by Walter H. Bucher. *Bull. Geol. Soc. America* (New York), Vol. 51, No. 4 (April 1, 1940), pp. 489–512.

*"Fabric Criteria for Distinguishing Pseudo Ripple Marks from Ripple Marks," by Earl Ingerson. *Ibid.*, pp. 557–70; 2 pls., 18 figs.

*"Screening Effect of Gravel on Unconsolidated Sands," by Ben Gumpertz. *Amer. Inst. Min. Met. Eng. Petrol. Technology*, Vol. 3, No. 1 (May, 1940). *Tech. Paper 1195*. 8 pp., 3 tables, 5 figs.

*"Factors Influencing Permeability Measurements," by Anders J. Carlson and Max C. Eastman. *Ibid. Tech. Paper 1196.* 6 pp., 1 table, 5 figs.

*"Colloid Chemistry of Clay Drilling Fluids," by A. G. Loomis, T. F. Ford, and J. F. Fidiam. *Ibid., Tech. Paper 1201.* 12 pp., 1 table, 8 figs.

*"A Preliminary Report on the Application of the Mass Spectrometer to Problems in the Petroleum Industry," by Herbert Hoover, Jr., and Harold Washburn. *Ibid., Tech. Paper 1205.* 7 pp., 3 figs.

*"Steady Flow of Gas-Oil-Water Mixtures through Unconsolidated Sands," by M. C. Leverett and W. B. Lewis. *Ibid., Tech. Paper 1206.* 9 pp., 3 tables, 9 figs.

*"Effects of Temperature and Pressure on Rheological Properties of Cement Slurries," by R. Floyd Farris. *Ibid., Tech. Paper 1207.* 14 pp., 8 figs.

*"Modern Drilling," by Wm. C. Bailey. *Summary of Operations California Oil Fields* (San Francisco), Vol. 23, No. 4 (April, May, June, 1938; issued, May, 1940), pp. 12–36; 3 pls.

*"Sedimentation," by Robert M. Bailey. "Relatively new geological science has promising possibilities." *Oil Weekly* (Houston), Vol. 97, No. 12 (May 27, 1940), pp. 27–40; 4 figs.

Gas Surveying, by V. A. Sokolov. Translated from Russian into English by A. A. Boehtlingk. 269 pp., 61 illus., 16 tables. 8.5×11 inches. "Describes the gas-surveying method of prospecting for crude oil and natural gas deposits which involves the determination of minute quantities of hydrocarbon vapors in the gases which permeate by diffusion from petroleum and natural gas deposits into the surface layers of the overlying soil." Limited supply. Order from A. A. Boehtlingk, 2022 Cedar Street, Berkeley, California. Price, $25.00.

*"Status of Geological and Geophysical Investigations on the Atlantic and Gulf Coastal Plain," by L. Don Leet. *Bull. Geol. Soc. America*, Vol. 51, No. 6 (New York, June 1, 1940), pp. 873–86; 2 figs.

MONTANA

*"Upper Cambrian Formations in Southern Montana," by Erling Dorf and Christina Lochman. *Bull. Geol. Soc. America* (New York), Vol. 51, No. 4 (April 1, 1940), pp. 541–56; 5 pls., 2 figs.

NEW MEXICO

*"Santa Fe Formation in the Española Valley, New Mexico," by Charles S. Denny. *Bull. Geol. Soc. America*, Vol. 51, No. 5 (New York, May 1, 1940), pp. 677–94; 4 pls., 2 figs.

PENNSYLVANIA AND MARYLAND

*"Crustal Shortening and Axial Divergence in the Appalachians of Southeastern Pennsylvania and Maryland," by Ernst Cloos. *Bull. Geol. Soc. America*, Vol. 51, No. 6 (New York, June 1, 1940), pp. 845–72; 9 figs.

SOUTH DAKOTA

*"Oil Possibilities of South Dakota still Unknown," by E. P. Rothrock. *Oil and Gas Jour.* (Tulsa), Vol. 39, No. 3 (May 30, 1940), pp. 18–19; 2 maps, 2 analyses, 1 photograph.

TEXAS

*"Stratigraphy and Structure of the Devil Ridge Area, Texas," by J. F. Smith, Jr. *Bull. Geol. Soc. America* (New York), Vol. 51, No. 4 (April 1, 1940), pp. 597–638; 6 pls., 7 figs.

TURKEY

*"Geological and Hydrological Observations on the Central Anatolian Low-Lying Plains," by W. Salomon-Calvi and H. Kleinsorge. *Maden Tetkik ve Arama Enstitüsü Mecmuasi*, Sene 5, Sayi 2/19 (Ankara, 1940), pp. 186–212; 4 figs. In German.

*"Sedimentary Beds of the Region of Erzincan," by V. Stchepinsky. *Ibid.*, pp. 222–33; map. In French.

*"Geological Structure of the Region of Erzurum," by Ervin Lahn. *Ibid.*, pp. 239–43. In French.

*"Notes on Drilling for Oil at Adana," by Cevat E. Tasman. *Ibid.*, pp. 244–47; 2 photographs. In Turkish. Summary in English, p. 247.

UTAH

*"Proterozoic (?) Rocks in Utah," by A. J. Eardley and R. A. Hatch. *Bull. Geol. Soc. America*, Vol. 51, No. 6 (New York, June 1, 1940), pp. 795–844; 6 figs.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Okla.), Vol. 14, No. 4 (July, 1940).

"Paleoecological Factors of Cretaceous Ammonoids," by Gayle Scott.

"A Miocene Microfauna of Haiti," by H. N. Coryell and Frances Charlton Rivero.

"Microscopic Pelmatozoa: Part 1, Ontogeny of the Blastoidea," by Carey Croneis and H. L. Geis.

"Studies of Carboniferous Ammonoids: Parts 1–4," by A. K. Miller and W. M. Furnish.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 7 (JULY, 1940), PP. 1343-1347

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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TWENTY-SIXTH ANNUAL MEETING, HOUSTON, APRIL 2–4, 1941

The executive committee of the Association has accepted the invitation of the Houston Geological Society to hold the twenty-sixth annual meeting in Houston, Texas. The dates selected are Wednesday, Thursday, and Friday, April 2, 3, and 4, 1941. The headquarters hotel is the Rice. Many will recall with pleasure memories of two earlier conventions in Houston, in 1924 and in 1933. The present officers of the Houston Geological Society are: president, Wallace C. Thompson, General Crude Oil Company; vice-president, Carleton D. Speed, Jr., Speed Oil Company; secretary, Olin G. Bell, Humble Oil and Refining Company; treasurer, A. P. Allison, Sun Oil Company.

Courtesy of Houston Chamber of Commerce

Aerial view of central business section of downtown Houston Texas. Three-wing building in lower right foreground is Rice Hotel, headquarters for twenty-sixth annual meeting of A.A.P.G., April 2, 3, and 4, 1941.

SUB-COMMITTEE ON CARBONIFEROUS

Last year the committee on geologic names and correlations created a subcommittee to study the nomenclature and classification of the Permian. C. W. Tomlinson was its chairman, and they completed their study and published their report in the *Bulletin*. They recommended that the Permian be advanced from the rank of series to system, which left the Pennsylvanian and Mississippian still as series since the old Carboniferous system included the Permian, Pennsylvanian, and Mississippian.

At its annual meeting in Chicago, the committee voted to form a subcommittee on the Carboniferous to study the matter of nomenclature and classification of the Pennsylvanian and Mississippian. This committee has

now been appointed and consists of M. G. Cheney, chairman, Robert H. Dott, Harold N. Hickey, Raymond C. Moore, Benjamin F. Hake, Norman D. Newell, Charles W. Tomlinson. The committee is composed of members of the full committee on geologic names and correlations, and, therefore, can not include many Permian and Mississippian authorities who are not members of the committee. The sub-committee in their work will need the help, advice, and constructive criticism of all students of the Carboniferous, and will consult with all interested parties if possible. They will try to simplify and improve the present nomenclature of the Pennsylvanian and Mississippian. No time limit has yet been set for this study since it is a difficult problem on which many men have worked and on which a vast amount of literature has been published. We ask that all geologists interested in this subject communicate with chairman Cheney, or with other members of the committee and give whatever help they can.

JOHN G. BARTRAM, *Chairman*
Committee on Geologic Names and Correlations

CORRECTION

DEVELOPMENTS IN ROCKY MOUNTAIN REGION IN 1939

Due to mechanical imperfection in reproducing Figure 2 on page 1103 of the article by C. E. Dobbin, "Developments in Rocky Mountain Region in 1939," two black spots erroneously appear in the southeast (lower right) corner of the map showing the oil and gas fields and main structural features of Wyoming. One spot is below the word "Hartville"; the other is below the symbol for "gas field" in the "explanation" column.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 7 (JULY, 1940), PP. 1348-1352

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

W. N. COGEN, of the Shell Oil Company, Inc., recently discussed "Comparison of Heavy Mineral Zones with Faunal Horizons in Louisiana Gulf Coast Cenozoic Sediments," before the Houston Geological Society.

WALTER K. LINK, recently geologist with the Standard Oil Company of Louisiana at Shreveport, is chief of exploration for the Standard Oil Company of New Jersey in Central America and the West Indies.

ROBERT F. WALTERS, who has been taking graduate work in the department of geology of The Johns Hopkins University for several years, has accepted a trainee position with the Gulf Oil Corporation at Wichita, Kansas.

MILTON W. CORBIN, who taught in the department of geology at Rutgers University last year, has been appointed co-ordinator between the Arkansas Geological Survey and the W.P.A. State Mineral Survey. His address is 416 Beech Street, Little Rock, Arkansas.

NORMAN PRATT is with the Coal Resources Survey, Tainui Street, Greymouth, New Zealand.

W. T. NIGHTINGALE, chief geologist of the Mountain Fuel Supply Company, Rock Springs, Wyoming, has been elected vice-president of the company.

A. A. HOLSTON, district geologist with the Stanolind Oil and Gas Company, has been transferred from Shreveport, Louisiana, to Jackson, Mississippi. He is succeeded at Shreveport by S. C. GEISEY.

EUGENE HOLMAN, head of South American producing operations, has been elected a director of the Standard Oil Company of New Jersey.

JOHN L. RICH, editor of the Association *Bulletin* from 1926 to 1928, and on the geological faculty of the University of Cincinnati since 1931, has been appointed head of the department of geology and geography at the University of Cincinnati.

JOHN B. LUCKE has resigned from the faculty of West Virginia University to accept an associate professorship in geology at the University of Connecticut. He will spend the month of July at the Beartooth Research Camp, Red Lodge, Montana, after which his address will be the University of Connecticut, Storrs, Connecticut.

DONALD J. MACNEIL, formerly with the Shell Oil Company, Inc., Tulsa, Oklahoma, has accepted a position with the McCall-Frontenac Company, Calgary, Alberta, Canada.

LOUIS C. CHAPPIUS, consulting geologist of Los Angeles, California, has been employed by Peruvian interests to map a large area in southern Peru.

MURRAY J. WELLS, geologist with the Indian Territory Illuminating Oil Company at Lawton, and JERRY B. NEWBY, consulting geologist at Oklahoma City, recently discussed the geology and drilling development of North Texas before the Oklahoma City Geological Society.

T. E. SWIGART, vice-president of the Shell Oil Company, Inc., Houston, Texas, is to succeed R. P. BASCOM (retiring) as president of the Shell Pipe Line Company.

A. J. GALLOWAY, vice-president in charge of production of the Shell Oil Company, Inc., St. Louis, Missouri, will move his headquarters to Houston, Texas.

The West Texas Geological Society will hold a one-day meeting at Midland, August 17, especially planned to be a home-coming for all geologists who have worked in West Texas. Approximately ten papers on West Texas subjects will form the technical program. A barbecue will complete the entertainment. The arrangements committee follows: general chairman, TAYLOR COLE, University Lands, Box 1663, Midland; program committee, E. RUSSELL LLOYD, R. E. KING, B. A. RAY, ROBERT I. DICKEY; entertainment, OSCAR R. CHAMPION, C. A. MIX, B. G. MARTIN, W. E. DAUGHERTY, W. S. MCCABE; arrangements, W. T. SCHNEIDER, W. LLOYD HASELTINE, ALVIN ATTAWAY, FRANK FULK, L. C. TENNIS; publicity, FRANK GARDNER.

The following officers have been elected to serve the Southwestern Geological Society, Austin, Texas, for the ensuing year: president, H. B. STENZEL, Bureau of Economic Geology; vice-president, WILLIAM A. BRAMLETTE, University of Texas department of geology; secretary-treasurer, TRAVIS PARKER, University of Texas department of geology.

A. I. LEVORSEN, of Tulsa, Oklahoma, has accepted appointment as an associate editor of the semi-quarterly journal *Economic Geology*.

PAUL M. BUTTERMORE has moved from Mt. Pleasant to East Lansing, Michigan. His post-office address is Box 131. He plans to continue his independent and consulting geological work from East Lansing.

J. C. POOLE, recently with the Barnsdall Oil Company, has opened offices in the Nixon Building, Corpus Christi, Texas, for consulting work in geology and appraisals.

HOWARD SAMUELL has resigned his position as resident geologist and petroleum engineer for the Peerless Oil and Gas Company at Fort Stockton, Texas, to become associated with Richardson Oils, Inc., as assistant to E. W. Sampson, superintendent, at Monahans, Texas.

W. C. MENDENHALL, director of the United States Geological Survey, Washington, D. C., has been appointed head of the oil resources division of the Defense Resources Committee.

J. A. CULBERTSON, geologist with the Continental Oil Company, Houston, recently presented a paper on "Downdip Wilcox of Coastal Texas and Louisiana" before the South Texas Geological Society at Corpus Christi.

H. D. HAND has moved from Effingham, Illinois, to Centralia. His address is Shell Oil Company, Inc., Box 476, Centralia, Illinois.

JOHN EMERY ADAMS, geologist for the Standard Oil Company of Texas, Midland, Texas, during the past 12 years, has been transferred to New Orleans, Louisiana. RICHARD D. WHITE, of the company's office at Houston, replaces Adams at Midland.

FRANK E. LOZO, JR., recently in the department of geology at Texas Christian University, Fort Worth, is employed by the Gulf Oil Corporation, at Midland, Texas.

GERALD ALBERT NORTHRIP, formerly with E. H. Moore, Inc., in Oklahoma, is with the Pure Oil Company, Wichita Falls, Texas.

J. M. CLARK has been transferred from the Tide Water Associated Oil Company's office in Tulsa to the Wichita Falls, Texas, office.

CLARENCE L. LEE has changed his business address from the Colombian Petroleum Company, Cucuta, Colombia, to The Texas Company, Apartado 78, Ciudad Bolivar, Venezuela.

EDWIN B. HOPKINS, vice-president of this association in 1934, died on July 5, 1940, following a heart attack at his home in Dallas, Texas. His age was 57 years.

The following changes have been announced for the geological department of the Phillips Petroleum Company, Bartlesville, Oklahoma. H. W. O'KEEFE has been appointed assistant chief geologist. T. E. WEIRICH is chief subsurface geologist. R. G. MOSS, formerly division geologist at Evansville, Indiana, is transferred to Bartlesville. HOMER H. CHARLES will have charge of geological work in North Dakota, South Dakota, and the northern Mid-Continent. G. F. SHEPHERD will have charge of Bartlesville office records on the Gulf Coast areas, formerly supervised by T. E. WEIRICH and J. K. KNOX. WALTER OLSON will be assistant geologist at Bartlesville for the Arkansas-North Louisiana-Mississippi region under supervision of T. E. Weirich. JOHN I. FERGUSON will be assistant geologist at Bartlesville for the Bartlesville, Oklahoma City, and Shawnee districts supervised by H. W. O'KEEFE.

JAMES L. TATUM, geologist for the Plymouth Oil Company at Sinton, Texas, discussed the oil industry of Mexico recently at a meeting of the South Texas Geological Society at Corpus Christi, Texas.

W. C. KINKEL, district geologist, and HUGH STOREY and W. G. CLARKSON, of the geological staff, have moved from San Angelo to the Midland, Texas, office of the Ohio Oil Company.

LESTER C. UREN, professor of petroleum engineering at the University of California, Berkeley, has been appointed acting dean of the college of mining, replacing the late Frank H. Probert.

E. L. ESTABROOK has established an office at Milano, Italy, temporarily to take the place of that maintained at The Hague, for the Standard Oil Company of New Jersey.

C. W. FLAGLER, formerly with the Danish American Prospecting Company, in Denmark, is now with the Gulf Oil Corporation in New York City.

J. E. Brantly, president of Drilling and Exploration Company, Inc., Los Angeles, California, has returned from South America.

FIELD TRIP

APPALACHIAN GEOLOGICAL SOCIETY

The executive committee of the Appalachian Geological Society has planned a field trip to be held some time in October for the purpose of studying the possibilities of deeper production in the Appalachian area from exposures in the Niagara Gorge and some distance east. Geologists from other parts of the country are invited. The trip is planned for two days with a dinner meeting and at least half a day in the Oriskany fields near the New York-Pennsylvania State line. Geologists interested in this trip are requested to send their names immediately to the president of the Appalachian Geological Society, J. R. Lockett, Ohio Fuel Gas Company, Box 117, Columbus, Ohio, who will place the names on a mailing list for the itinerary and other details. An indication of the number of persons interested is necessary to make arrangements.

FIELD TRIP

KANSAS GEOLOGICAL SOCIETY, AUGUST 26–SEPTEMBER 1

The Fourteenth Annual Field Conference of the Kansas Geological Society will be held in the Black Hills of South Dakota, the Hartville uplift, Laramie Mountains, and Medicine Bow Range of Wyoming, August 26 to September 1. S. H. Knight, head of the department of geology, University of Wyoming, and State geologist, is director. He will be ably assisted by men familiar with the details of the stratigraphy and structure of this most interesting area.

Increased interest in the subsurface stratigraphy of the Great Plains, principally Nebraska and South Dakota, and in the Pennsylvanian production in the Lance Creek field of eastern Wyoming assures a large attendance. Special emphasis will be placed on the Cambro-Ordovician and Permo-Pennsylvanian rocks. Correlations with the Mid-Continent and central Wyoming regions will be advanced. Further information may be secured from the office of the Kansas Geological Society, 412 Union National Bank Building, Wichita, Kansas.

The general itinerary follows.

Aug. 25, Sun. P.M.	Convene at Rapid City, South Dakota.
26, Mon. A.M.	Rapid City. Proceed to northern Black Hills. Whitewood-Deadwood problem. Permo-Pennsylvanian beds. Homestake mine. Night at Rapid City.
27, Tues. A.M.	Rapid City. Central and southern Black Hills. Night at Hot Springs.
28, Wed. A.M.	Hot Springs. Central and southern Black Hills. Night at Lusk, Wyoming.
29, Thurs. A.M.	Lusk, Wyoming. Permo-Pennsylvanian of Hartville uplift. Night at Lusk.
30, Fri. A.M.	Lusk. Hartville uplift. Night at Douglas.
31, Sat. A.M.	Douglas. Sections south of Douglas. Big Muddy oil field and Jacksons Canyon in P.M. Night at Casper.
Sept. 1, Sun. A.M.	Casper. Alcova Dam. Seminoe Plateau. Hanna Basin. Walcott. Saratoga. Medicine Bow Mountains. Possibly might stop at summer camp of University of Wyoming.
2, Mon.	Symposium on Permian problems.

Private automobiles will be used for transportation. For persons without cars, the committee will undertake to provide seats in the cars of other participants.

The registration fee is $12.50 and includes the price of one copy of the guide book. Additional copies of the guide book may be purchased for $7.50. All participants must pay the registration fee, no matter how much of the conference they attend. Further information may be secured from the office of the Kansas Geological Society, 412 Union National Bank Building, Wichita, Kansas.

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The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

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Meetings: First and third Wednesdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Thursday (October-May), Michaelis Cafeteria, 507 South Boulder Avenue.

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Magnolia Petroleum Company, Box 780

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Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

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Snowden and McSweeney Company

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The Pure Oil Company, Box 2107

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

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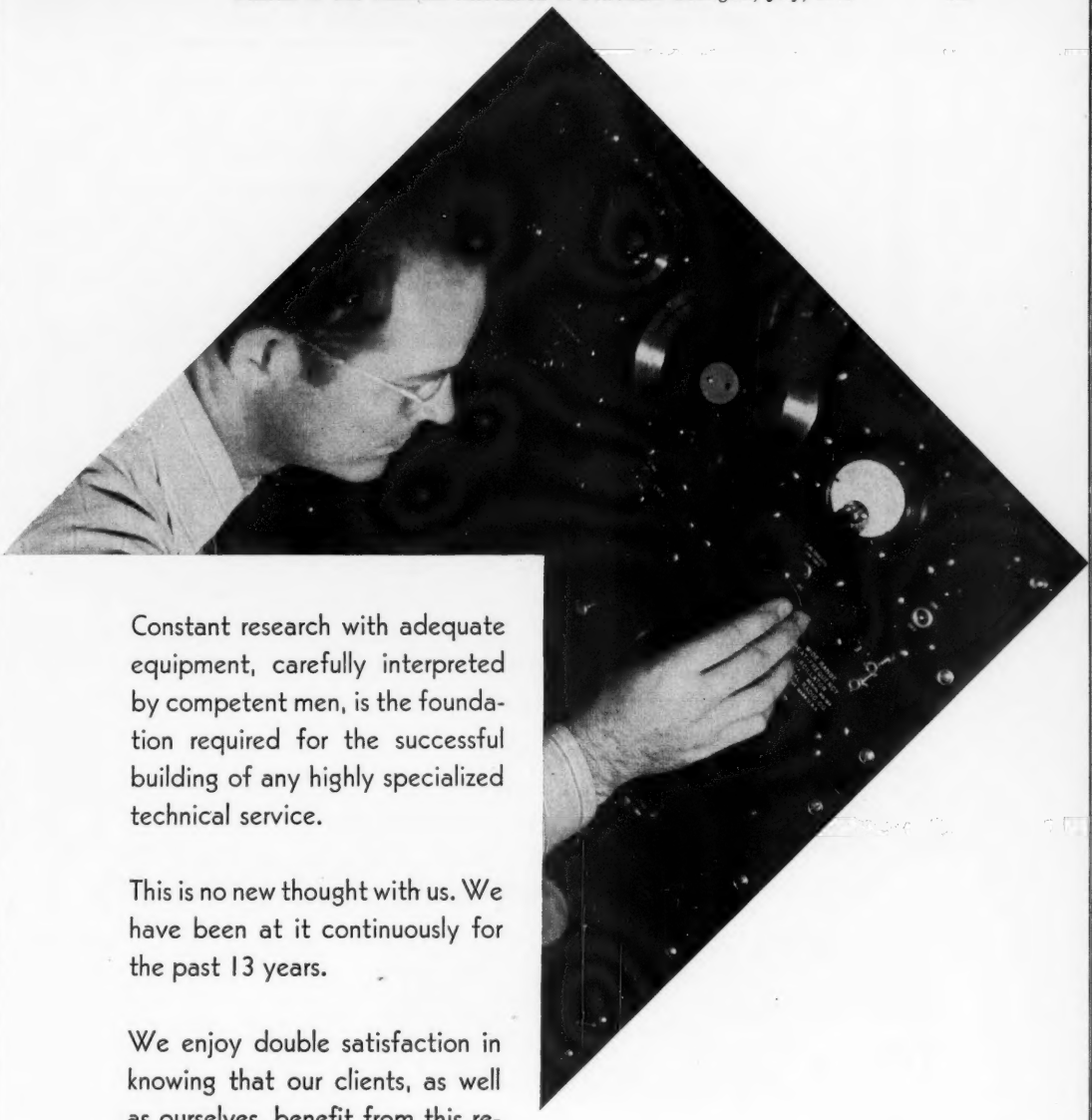

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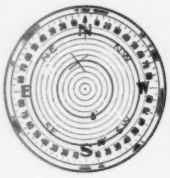

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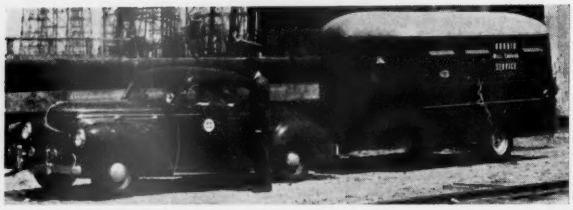

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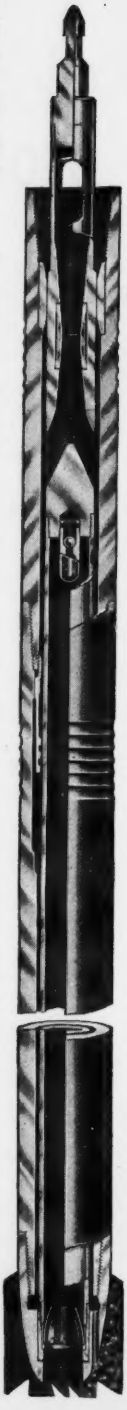

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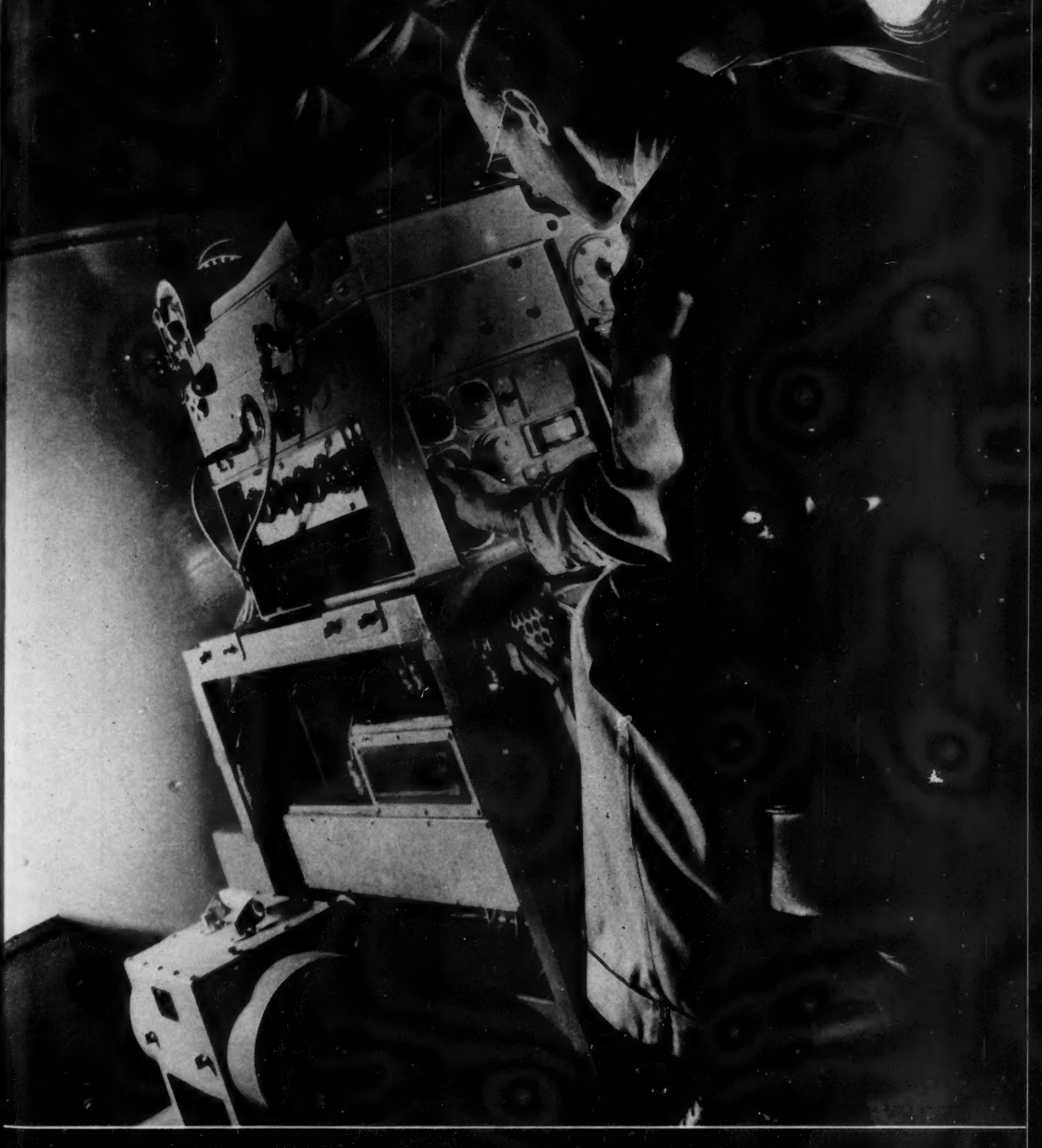

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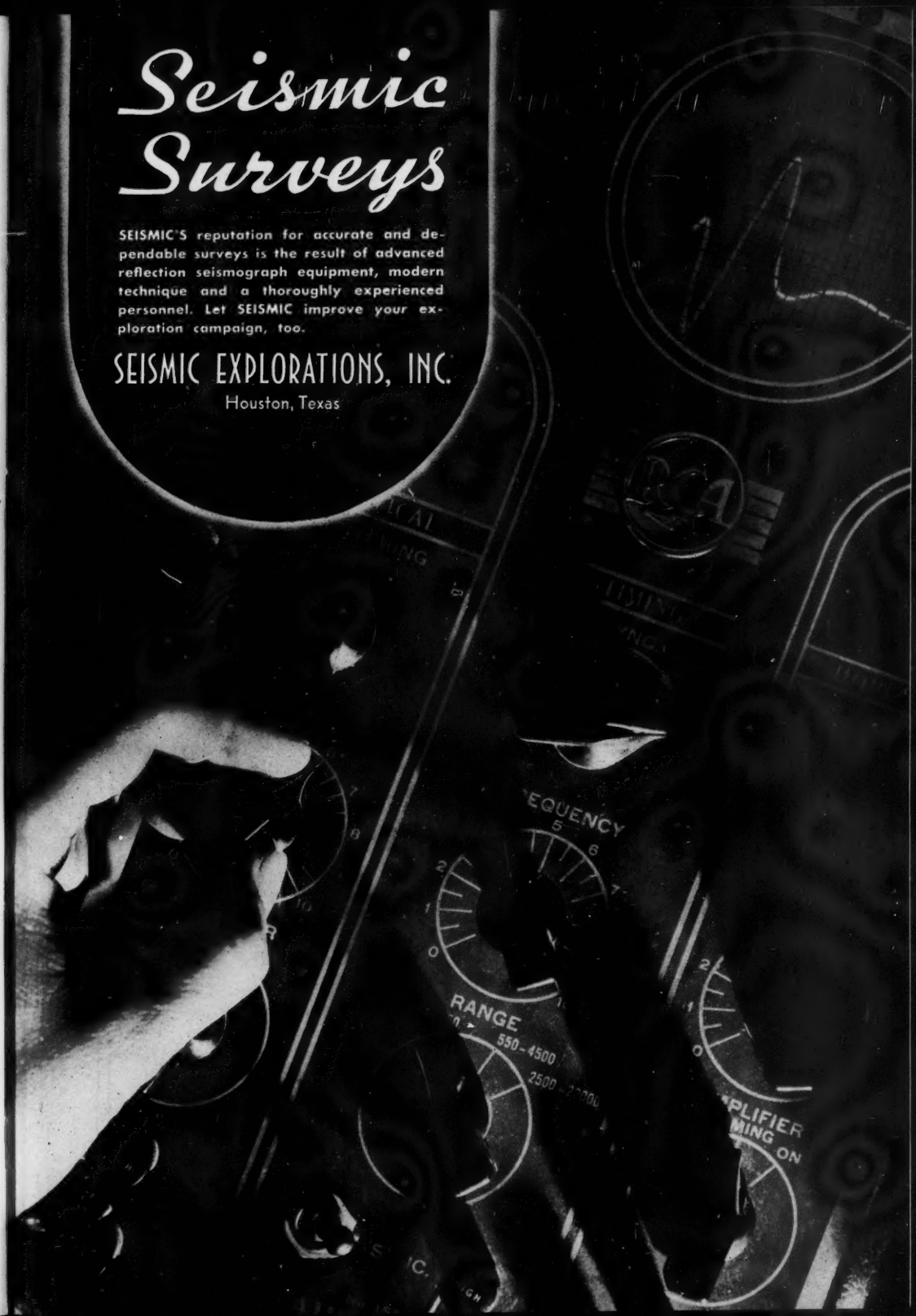
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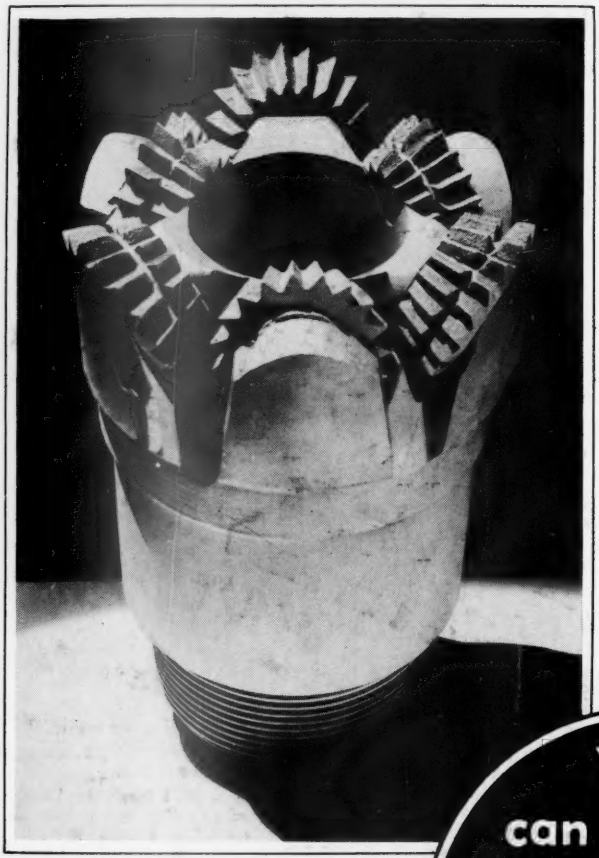

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